CARNEGIE INSTITUTION OF WASHINGTON

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With Administrative Reports through December 9, 1955

CARNEGIE INSTITUTION OF WASHINGTON
WASHINGTON, D. C.
1955

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CONTENTS

FORMER PRESIDENTS AND TRUSTEES

PRESIDENTS

TRUSTEES

Besides the names enumerated above, the following were ex-officio members of the Board of Trustees under the original charter, from the date of organization until April 28, 1904: the President of the United States, the President of the Senate, the Speaker of the House of Representatives, the Secretary of the Smithsonian Institution, the President of the National Academy of Sciences.

STAFF OF INVESTIGATORS FOR THE YEAR 1955

ASTRONOMY

Mount Wilson and Palomar Observatories

813 Santa Barbara Street, Pasadena 4, California

Mount Wilson Observatory organized in 1904; George E. Hale, Director 1904–1923, Honorary Director 1923–1936; Walter S. Adams, Director 1924–1945. Unified operation with the Palomar Observatory of the California Institute of Technology began in 1948.

Ira S. Bowen, *Director*
Walter Baade
Horace W. Babcock
William A. Baum
Armin J. Deutsch
Jesse L. Greenstein
Milton L. Humason
Rudolph L. Minkowski
Guido Münch
Seth B. Nicholson
Donald E. Osterbrock
*Edison Pettit
Robert S. Richardson
Allan R. Sandage
Olin C. Wilson
Fritz Zwicky

TERRESTRIAL SCIENCES

Geophysical Laboratory

2801 Upton Street, N.W., Washington 8, D. C.

Organized in 1906, opened in 1907; Arthur L. Day, Director 1909–1936; Leason H. Adams, Acting Director 1936–1937, Director 1938–1952; George W. Morey, Acting Director 1952–1953.

Philip H. Abelson, *Director*
Francis R. Boyd, Jr.
Felix Chayes
Gordon L. Davis
Gabrielle Donnay
Joseph L. England
Hans P. Eugster
Joseph W. Greig
Frank C. Kracek
Gunnar Kullerud
William S. MacKenzie
George W. Morey
J. Frank Schairer
Hatten S. Yoder, Jr.

Research Associates
Hans Ramberg
C. E. Tilley

Staff Associate
Gordon J. F. MacDonald

Visiting Investigator
David B. Stewart

Department of Terrestrial Magnetism

5241 Broad Branch Road, N.W., Washington 15, D. C.

Organized in 1904; Louis A. Bauer, Director 1904–1929; John A. Fleming, Acting Director 1929–1934, Director 1935–1946.

Merle A. Tuve, *Director*
L. Thomas Aldrich
Ellis T. Bolton
Roy J. Britten
Bernard F. Burke
Dean B. Cowie
John W. Firor
Scott E. Forbush
John W. Graham
Norman P. Heydenburg
‡Ellis A. Johnson
Richard B. Roberts
Howard E. Tatel
Georges M. Temmer
George R. Tilton
Ernest H. Vestine
Harry W. Wells
George W. Wetherill

Visiting Investigators
E. H. Creaser
§William R. Duryee
K. L. Franklin
H. Lawrence Helfer
§P. M. Jeffery
§R. D. McAfee
§G. H. Munro
Irena Z. Roberts
§M. Sugiura

* Retired in 1955.
‡ On leave of absence.
§ Term of appointment completed in 1955.

BIOLOGICAL SCIENCES

Department of Plant Biology

Stanford, California

Desert Laboratory, opened in 1903, became headquarters of Department of Botanical Research in 1905; name changed to Laboratory for Plant Physiology in 1923; Daniel T. MacDougal, Director 1906–1927. Reorganized in 1928 as Division of Plant Biology, including Ecology; Herman A. Spoehr, Chairman 1927–1930 and 1931–1947, Chairman Emeritus 1947–1950. Name changed to Department of Plant Biology in 1951.

C. Stacy French, *Director*
Jens C. Clausen
William M. Hiesey
Harold W. Milner
Malcolm A. Nobs
James H. C. Smith

Visiting Investigators

Elias Landolt
Harlan Lewis

Department of Embryology

Wolfe and Madison Streets, Baltimore 5, Maryland

Organized in 1914; Franklin P. Mall, Director 1914–1917; George L. Streeter, Director 1918–1940.

George W. Corner, *Director*
James D. Ebert, *Director,* January 1, 1956
David W. Bishop
Bent G. Böving
Robert K. Burns
Arpad Csapo
*Samuel R. M. Reynolds

Consultant

George W. Bartelmez

Research Associates

Arthur T. Hertig
Chester H. Heuser
Elizabeth M. Ramsey
Samuel R. M. Reynolds

Department of Genetics

Cold Spring Harbor, Long Island, New York

Station for Experimental Evolution opened in 1904; named changed to Department of Experimental Evolution in 1906; combined with Eugenics Record Office in 1921 to form Department of Genetics. Charles B. Davenport, Director 1904–1934; Albert F. Blakeslee, Director 1935–1941.

Milislav Demerec, *Director*
Alfred D. Hershey
Berwind P. Kaufmann
Barbara McClintock
Margaret R. McDonald
*Evelyn M. Witkin

Research Associate

Evelyn M. Witkin

Special Investigators

Elizabeth Burgi
Royston C. Clowes
‡Alan Garen
Helen Gay
‡Philip E. Hartman
‡Dusan Kanazir
Ernest L. Lahr
Joseph D. Mandell
Norman E. Melechen
Hermann Moser
Derek A. Smith

ARCHAEOLOGY

Department of Archaeology

10 Frisbie Place, Cambridge 38, Massachusetts

Department of Historical Research organized in 1903; Andrew C. McLaughlin, Director 1903–1905; J. Franklin Jameson, Director 1905–1928. In 1930 this Department was incorporated as a section of United States history in a new Division of Historical Research; Alfred V. Kidder, Chairman 1930–1950. Name changed to Department of Archaeology in 1951.

Harry E. D. Pollock, *Director*
*Margaret W. Harrison, *Editor*
§Earl H. Morris
Tatiana Proskouriakoff
Karl Ruppert
Anna O. Shepard
Edwin M. Shook
A. Ledyard Smith
Robert E. Smith
Gustav Strömsvik
J. Eric S. Thompson

RESEARCH ASSOCIATES of the CARNEGIE INSTITUTION OF WASHINGTON

Louis B. Flexner, University of Pennsylvania
Willard F. Libby, University of Chicago
John von Neumann, Institute for Advanced Study

* Resigned in 1955.
‡ Term of appointment completed in 1955.
§ Retired in 1955.

OFFICE OF ADMINISTRATION

Caryl P. Haskins, *President*
Paul A. Scherer, *Executive Officer*
Samuel Callaway, *Assistant to the President*
Ailene J. Bauer, *Director of Publications*
Dorothy R. Swift, *Editor*
Earle B. Biesecker, *Bursar*
James W. Boise, *Assistant Bursar*
James F. Sullivan, *Assistant to the Bursar*
Richard F. F. Nichols, *Executive Assistant to the Finance Committee*

Officers of Retirement Fund

Earle B. Biesecker, *Secretary-Treasurer*
James W. Boise, *Assistant Treasurer*

ORGANIZATION, PLAN, AND SCOPE

The Carnegie Institution of Washington was founded by Andrew Carnegie, January 28, 1902, when he gave to a board of trustees an endowment of registered bonds of the par value of ten million dollars. To this fund an addition of two million dollars was made by Mr. Carnegie on December 10, 1907, and a further addition of ten million dollars was made by him on January 19, 1911. Furthermore, the income of a reserve fund of about three million dollars, accumulated in accordance with the founder's specifications in 1911, is now available for general use, and in recent years a total of ten million dollars has been paid by the Carnegie Corporation of New York as increase to the Endowment Fund of the Institution. The Institution was originally organized under the laws of the District of Columbia and incorporated as the *Carnegie Institution,* articles of incorporation having been executed on January 4, 1902. The Institution was reincorporated, however, by an act of the Congress of the United States, approved April 28, 1904, under the title of *Carnegie Institution of Washington.* (See existing Articles of Incorporation on following pages.)

Organization under the new Articles of Incorporation was effected May 18, 1904, and the Institution was placed under the control of a board of twenty-four trustees, all of whom had been members of the original corporation. The trustees meet annually in December to consider the affairs of the Institution in general, the progress of work already undertaken, and the initiation of new projects, and to make the necessary appropriations for the ensuing year. During the intervals between the meetings of the trustees the affairs of the Institution are conducted by an Executive Committee chosen by and from the Board of Trustees and acting through the President of the Institution as chief executive officer.

The Articles of Incorporation of the Institution declare in general "that the objects of the corporation shall be to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind."

The Institution is essentially an operating organization. It attempts to advance fundamental research in fields not normally covered by the activities of other agencies, and to concentrate its attention upon specific problems, with the idea of shifting attack from time to time to meet the more pressing needs of research as they develop with increase of knowledge. Some of these problems require the collaboration of several investigators, special equipment, and continuous effort. Many close relations exist among activities of the Institution, and a type of organization representing investigations in astronomy, in terrestrial sciences, in biological sciences, and in archaeology has been effected. Conference groups on various subjects have played a part in bringing new vision and new methods to bear upon many problems. Constant efforts are made to facilitate interpretation and application of results of research activities of the Institution.

ARTICLES OF INCORPORATION

Public No. 260. An Act to incorporate the Carnegie Institution of Washington.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the persons following, being persons who are now trustees of the Carnegie Institution, namely, Alexander Agassiz, John S. Billings, John L. Cadwalader, Cleveland H. Dodge, William N. Frew, Lyman J. Gage, Daniel C. Gilman, John Hay, Henry L. Higginson, William Wirt Howe, Charles L. Hutchinson, Samuel P. Langley, William Lindsay, Seth Low, Wayne MacVeagh, Darius O. Mills, S. Weir Mitchell, William W. Morrow, Ethan A. Hitchcock, Elihu Root, John C. Spooner, Andrew D. White, Charles D. Walcott, Carroll D. Wright, their associates and successors, duly chosen, are hereby incorporated and declared to be a body corporate by the name of the Carnegie Institution of Washington and by that name shall be known and have perpetual succession, with the powers, limitations, and restrictions herein contained.

Sec. 2. That the objects of the corporation shall be to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind; and in particular—

(a) To conduct, endow, and assist investigation in any department of science, literature, or art, and to this end to cooperate with governments, universities, colleges, technical schools, learned societies, and individuals.

(b) To appoint committees of experts to direct special lines of research.

(c) To publish and distribute documents.

(d) To conduct lectures, hold meetings, and acquire and maintain a library.

(e) To purchase such property, real or personal, and construct such building or buildings as may be necessary to carry on the work of the corporation.

(f) In general, to do and perform all things necessary to promote the objects of the institution, with full power, however, to the trustees hereinafter appointed and their successors from time to time to modify the conditions and regulations under which the work shall be carried on, so as to secure the application of the funds in the manner best adapted to the conditions of the time, provided that the objects of the corporation shall at all times be among the foregoing or kindred thereto.

Sec. 3. That the direction and management of the affairs of the corporation and the control and disposal of its property and funds shall be vested in a board of trustees, twenty-two in number, to be composed of the following individuals: Alexander Agassiz, John S. Billings, John L. Cadwalader, Cleveland H. Dodge, William N. Frew, Lyman J. Gage, Daniel C. Gilman, John Hay, Henry L. Higginson, William Wirt Howe, Charles L. Hutchinson, *Samuel P. Langley,* William Lindsay, Seth Low, Wayne MacVeagh, Darius O. Mills, S. Weir Mitchell, William W. Morrow, *Ethan A. Hitchcock,* Elihu Root, John C. Spooner, Andrew D. White, Charles D. Walcott, Carroll D. Wright, who shall constitute the first board of trustees. The board of trustees shall have power from time to time to increase its membership to not more than twenty-seven members. Vacancies occasioned by death, resignation, or otherwise shall be filled by the remaining trustees in such manner as the by-laws

shall prescribe; and the persons so elected shall thereupon become trustees and also members of the said corporation. The principal place of business of the said corporation shall be the city of Washington, in the District of Columbia.

SEC. 4. That such board of trustees shall be entitled to take, hold, and administer the securities, funds, and property so transferred by said Andrew Carnegie to the trustees of the Carnegie Institution and such other funds or property as may at any time be given, devised, or bequeathed to them, or to such corporation, for the purposes of the trust; and with full power from time to time to adopt a common seal, to appoint such officers, members of the board of trustees or otherwise, and such employees as may be deemed necessary in carrying on the business of the corporation, at such salaries or with such remuneration as they may deem proper; and with full power to adopt by-laws from time to time and such rules or regulations as may be necessary to secure the safe and convenient transaction of the business of the corporation; and with full power and discretion to deal with and expend the income of the corporation in such manner as in their judgment will best promote the objects herein set forth and in general to have and use all powers and authority necessary to promote such objects and carry out the purposes of the donor. The said trustees shall have further power from time to time to hold as investments the securities hereinabove referred to so transferred by Andrew Carnegie, and any property which has been or may be transferred to them or such corporation by Andrew Carnegie or by any other person, persons, or corporation, and to invest any sums or amounts from time to time in such securities and such form and manner as are permitted to trustees or to charitable or literary corporations for investment, according to the laws of the States of New York, Pennsylvania, or Massachusetts, or in such securities as are authorized for investment by the said deed of trust so executed by Andrew Carnegie, or by any deed of gift or last will and testament to be hereafter made or executed.

SEC. 5. That the said corporation may take and hold any additional donations, grants, devises, or bequests which may be made in further support of the purposes of the said corporation, and may include in the expenses thereof the personal expenses which the trustees may incur in attending meetings or otherwise in carrying out the business of the trust, but the services of the trustees as such shall be gratuitous.

SEC. 6. That as soon as may be possible after the passage of this Act a meeting of the trustees hereinbefore named shall be called by Daniel C. Gilman, John S. Billings, Charles D. Walcott, S. Weir Mitchell, John Hay, Elihu Root, and Carroll D. Wright, or any four of them, at the city of Washington, in the District of Columbia, by notice served in person or by mail addressed to each trustee at his place of residence; and the said trustees, or a majority thereof, being assembled, shall organize and proceed to adopt by-laws, to elect officers and appoint committees, and generally to organize the said corporation; and said trustees herein named, on behalf of the corporation hereby incorporated, shall thereupon receive, take over, and enter into possession, custody, and management of all property, real or personal, of the corporation heretofore known as the Carnegie Institution, incorporated, as hereinbefore set forth under "An Act to establish a Code of Law for the District of Columbia, January fourth, nineteen hundred and two," and to all its rights, contracts, claims, and property of any kind or nature; and the several officers of such corporation, or

any other person having charge of any of the securities, funds, real or personal, books, or property thereof, shall, on demand, deliver the same to the said trustees appointed by this Act or to the persons appointed by them to receive the same; and the trustees of the existing corporation and the trustees herein named shall and may take such other steps as shall be necessary to carry out the purposes of this Act.

SEC. 7. That the rights of the creditors of the said existing corporation known as the Carnegie Institution shall not in any manner be impaired by the passage of this Act, or the transfer of the property hereinbefore mentioned, nor shall any liability or obligation for the payment of any sums due or to become due, or any claim or demand, in any manner or for any cause existing against the said existing corporation, be released or impaired; but such corporation hereby incorporated is declared to succeed to the obligations and liabilities and to be held liable to pay and discharge all of the debts, liabilities, and contracts of the said corporation so existing to the same effect as if such new corporation had itself incurred the obligation or liability to pay such debt or damages, and no such action or proceeding before any court or tribunal shall be deemed to have abated or been discontinued by reason of the passage of this Act.

SEC. 8. That Congress may from time to time alter, repeal, or modify this Act of incorporation, but no contract or individual right made or acquired shall thereby be divested or impaired.

SEC. 9. That this Act shall take effect immediately.

Approved, April 28, 1904

BY-LAWS OF THE INSTITUTION

Adopted December 13, 1904. Amended December 13, 1910, December 13, 1912, December 10, 1937, December 15, 1939, December 13, 1940, December 18, 1942, December 12, 1947, and December 10, 1954

Article I

THE TRUSTEES

1. The Board of Trustees shall consist of twenty-four members, with power to increase its membership to not more than twenty-seven members. The Trustees shall hold office continuously and not for a stated term.

2. In case any Trustee shall fail to attend three successive annual meetings of the Board he shall thereupon cease to be a Trustee.

3. No Trustee shall receive any compensation for his services as such.

4. All vacancies in the Board of Trustees shall be filled by the Trustees by ballot at an annual meeting, but no person shall be declared elected unless he receives the votes of two-thirds of the Trustees present.

Article II

OFFICERS OF THE BOARD

1. The officers of the Board shall be a Chairman of the Board, a Vice-Chairman, and a Secretary, who shall be elected by the Trustees, from the members of the Board, by ballot to serve for a term of three years. All vacancies shall be filled by the Board for the unexpired term; provided, however, that the Executive Committee shall have power to fill a vacancy in the office of Secretary to serve until the next meeting of the Board of Trustees.

2. The Chairman shall preside at all meetings and shall have the usual powers of a presiding officer.

3. The Vice-Chairman, in the absence or disability of the Chairman, shall perform the duties of the Chairman.

4. The Secretary shall issue notices of meetings of the Board, record its transactions, and conduct that part of the correspondence relating to the Board and to his duties.

Article III

EXECUTIVE ADMINISTRATION

The President

1. There shall be a President who shall be elected by ballot by, and hold office during the pleasure of, the Board, who shall be the chief executive officer of the Institution. The President, subject to the control of the Board and the Executive Committee, shall have general charge of all matters of administration and supervision of all arrangements for research and other work undertaken by the Institution or with its funds. He shall prepare and submit to the Board of Trustees and to the Executive

Committee plans and suggestions for the work of the Institution, shall conduct its general correspondence and the correspondence with applicants for grants and with the special advisers of the Committee, and shall present his recommendations in each case to the Executive Committee for decision. All proposals and requests for grants shall be referred to the President for consideration and report. He shall have power to remove, appoint, and, within the scope of funds made available by the Trustees, provide for compensation of subordinate employees and to fix the compensation of such employees within the limits of a maximum rate of compensation to be established from time to time by the Executive Committee. He shall be *ex officio* a member of the Executive Committee.

2. He shall be the legal custodian of the seal and of all property of the Institution whose custody is not otherwise provided for. He shall sign and execute on behalf of the corporation all contracts and instruments necessary in authorized administrative and research matters and affix the corporate seal thereto when necessary, and may delegate the performance of such acts and other administrative duties in his absence to the Executive Officer. He may execute all other contracts, deeds, and instruments on behalf of the corporation and affix the seal thereto when expressly authorized by the Board of Trustees or Executive Committee. He may, within the limits of his own authorization, delegate to the Executive Officer authority to act as custodian of and affix the corporate seal. He shall be responsible for the expenditure and disbursement of all funds of the Institution in accordance with the directions of the Board and of the Executive Committee, and shall keep accurate accounts of all receipts and disbursements. Following approval by the Executive Committee he shall transmit to the Board of Trustees before its annual meeting in December a written report of the operations and business of the Institution for the preceding fiscal year with his recommendations for work and appropriations for the succeeding calendar year.

3. He shall attend all meetings of the Board of Trustees.

4. There shall be an officer designated Executive Officer who shall be appointed by and hold office at the pleasure of the President, subject to the approval of the Executive Committee. His duties shall be to assist and act for the President as the latter may duly authorize and direct.

5. The President shall retire from office at the end of the calendar year in which he becomes sixty-five years of age.

Article IV

MEETINGS

1. The annual meeting of the Board of Trustees shall be held in the City of Washington, in the District of Columbia, on the first Friday following the second Thursday of December in each year unless the date and place of meeting are otherwise ordered by the Executive Committee.

2. Special meetings of the Board may be called by the Executive Committee by notice served personally upon, or mailed to the usual address of, each Trustee twenty days prior to the meeting.

3. Special meetings shall, moreover, be called in the same manner by the Chairman upon the written request of seven members of the Board.

Article V

COMMITTEES

1. There shall be the following standing Committees, *viz.* an Executive Committee, a Finance Committee, an Auditing Committee, a Nominating Committee, and a Retirement Committee.

2. All vacancies occurring in the Executive Committee, the Finance Committee, the Auditing Committee, the Nominating Committee, and the Retirement Committee shall be filled by the Trustees at the next regular meeting. In case of vacancy in the Finance Committee, the Auditing Committee, the Nominating Committee, or the Retirement Committee, upon request of the remaining members of such committee, the Executive Committee may fill such vacancy by appointment until the next meeting of the Board of Trustees.

3. The terms of all officers and of all members of committees, as provided for herein, shall continue until their successors are elected or appointed.

Executive Committee

4. The Executive Committee shall consist of the Chairman, Vice-Chairman, and Secretary of the Board of Trustees and the President of the Institution *ex officio* and, in addition, five trustees to be elected by the Board by ballot for a term of three years, who shall be eligible for re-election. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term.

5. The Executive Committee shall, when the Board is not in session and has not given specific directions, have general control of the administration of the affairs of the corporation and general supervision of all arrangements for administration, research, and other matters undertaken or promoted by the Institution. It shall also submit to the Board of Trustees a printed or typewritten report of each of its meetings, and at the annual meeting shall submit to the Board a report for publication.

6. The Executive Committee shall have power to authorize the purchase, sale, exchange, or transfer of real estate.

Finance Committee

7. The Finance Committee shall consist of not less than five and not more than six members to be elected by the Board of Trustees by ballot for a term of three years, who shall be eligible for re-election.

8. The Finance Committee shall have custody of the securities of the corporation and general charge of its investments and invested funds, including its investments and invested funds as trustee of any retirement plan for the Institution's staff members and employees, and shall care for and dispose of the same subject to the directions of the Board of Trustees. It shall have power to authorize the purchase, sale, exchange, or transfer of securities and to delegate this power. It shall consider and recommend to the Board from time to time such measures as in its opinion will promote the financial interests of the Institution and of the trust fund under any retirement plan for the Institution's staff members and employees, and shall make a report at each meeting of the Board.

Auditing Committee

9. The Auditing Committee shall consist of three members to be elected by the Board of Trustees by ballot for a term of three years.

10. Before each annual meeting of the Board of Trustees, the Auditing Committee shall cause the accounts of the Institution for the preceding fiscal year to be audited by public accountants. The accountants shall report to the Committee, and the Committee shall present said report at the ensuing annual meeting of the Board with such recommendations as the Committee may deem appropriate.

Nominating Committee

11. The Nominating Committee shall consist of the Chairman of the Board of Trustees *ex officio* and, in addition, three trustees to be elected by the Board by ballot for a term of three years, who shall not be eligible for re-election until after the lapse of one year. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term, provided that of the Nominating Committee first elected after adoption of this By-Law one member shall serve for one year, one member shall serve for two years, and one member shall serve for three years, the Committee to determine the respective terms by lot.

12. Sixty days prior to an annual meeting of the Board the Nominating Committee shall notify the Trustees by mail of the vacancies to be filled in membership of the Board. Each Trustee may submit nominations for such vacancies. Nominations so submitted shall be considered by the Nominating Committee, and ten days prior to the annual meeting the Nominating Committee shall submit to members of the Board by mail a list of the persons so nominated, with its recommendations for filling existing vacancies on the Board and its Standing Committees. No other nominations shall be received by the Board at the annual meeting except with the unanimous consent of the Trustees present.

Retirement Committee

13. The Retirement Committee shall consist of three members to be elected by the Board of Trustees by ballot for a term of three years, who shall be eligible for re-election. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term, provided that of the Retirement Committee first elected after adoption of this By-Law one member shall serve for one year, one member shall serve for two years, and one member shall serve for three years, the Committee to determine the respective terms by lot.

14. The Retirement Committee shall, subject to the directions of the Board of Trustees, be responsible for the maintenance of a retirement plan for staff members and employees of the Institution and act for the Institution in its capacity as trustee under any such plan, except that any matter relating to investments under any such plan shall be the responsibility of the Finance Committee subject to the directions of the Board of Trustees. The Committee shall submit a report to the Board at the annual meeting of the Board.

Article VI

FINANCIAL ADMINISTRATION

1. No expenditure shall be authorized or made except in pursuance of a previous appropriation by the Board of Trustees, or as provided in Article V, paragraph 8, hereof.

2. The fiscal year of the Institution shall commence on the first day of July in each year.

3. The Executive Committee shall submit to the annual meeting of the Board a full statement of the finances and work of the Institution for the preceding fiscal year and a detailed estimate of the expenditures of the succeeding calendar year.

4. The Board of Trustees, at the annual meeting in each year, shall make general appropriations for the ensuing calendar year; but nothing contained herein shall prevent the Board of Trustees from making special appropriations at any meeting.

5. The Executive Committee shall have general charge and control of all appropriations made by the Board. Following the annual meeting each year, the Executive Committee may make allotment of funds for the period from January 1 to termination of the fiscal year on June 30. It may also make allotment of funds for the period from July 1 to December 31 in advance of July 1. The Committee shall, however, have full authority for allotment of available funds to meet necessary expenditures by other methods, if desirable, and transfer of balances to meet special needs. It shall make provision for outstanding obligations and for revertment of unexpended balances at termination of the fiscal year.

6. The securities of the Institution and evidences of property, and funds invested and to be invested, shall be deposited in such safe depository or in the custody of such trust company and under such safeguards as the Finance Committee shall designate, subject to directions of the Board of Trustees. Income of the Institution available for expenditure shall be deposited in such banks or depositories as may from time to time be designated by the Executive Committee.

7. Any trust company entrusted with the custody of securities by the Finance Committee may, by resolution of the Board of Trustees, be made Fiscal Agent of the Institution, upon an agreed compensation, for the transaction of the business coming within the authority of the Finance Committee.

Article VII

AMENDMENT OF BY-LAWS

1. These by-laws may be amended at any annual or special meeting of the Board of Trustees by a two-thirds vote of the members present, provided written notice of the proposed amendment shall have been served personally upon, or mailed to the usual address of, each member of the Board twenty days prior to the meeting.

ABSTRACT OF MINUTES OF THE FIFTY-SEVENTH MEETING OF THE BOARD OF TRUSTEES

The annual meeting of the Board of Trustees was held in Washington, D. C., on Friday, December 9, 1955. The Chairman, Mr. Root, presided.

The following Trustees were in attendance: Robert Woods Bliss, Omar N. Bradley, W. Cameron Forbes, Walter S. Gifford, Crawford H. Greenewalt, Caryl P. Haskins, Barklie Henry, Ernest O. Lawrence, Alfred L. Loomis, Keith S. McHugh, Henry S. Morgan, William I. Myers, Henning W. Prentis, Jr., Elihu Root, Jr., Henry R. Shepley, Charles P. Taft, Juan T. Trippe, and Robert E. Wilson. The President of the Institution, Vannevar Bush, was also present.

The minutes of the fifty-sixth meeting were approved.

The Chairman announced the resignation of Roswell Miller during the past year. In accordance with the recommendation of the Nominating Committee, Margaret Carnegie Miller was unanimously elected a member of the Board of Trustees to fill this vacancy and, upon invitation, then joined the Trustees for the remainder of the meeting.

W. Cameron Forbes tendered his resignation as a Trustee, completing thirty-five years' service on the Board. His resignation was accepted with regret.

Reports of the President, the Executive Committee, the Finance Committee, the Retirement Committee, the Auditor, the Auditing Committee, and the Nominating Committee, and of the Directors of Departments and Research Associates of the Institution were presented and considered.

The sum of $1,997,235 was appropriated for the calendar year 1956 for expenditure under the general charge and control of the Executive Committee.

Following recommendations of the Nominating Committee, Henning W. Prentis, Jr. was re-elected a member of the Executive Committee for a three-year term, and Walter S. Gifford was elected a member of the Executive Committee for the remainder of the term of Dr. Haskins, who takes office as President and as an ex-officio member of the Executive Committee on January 1, 1956. Keith S. McHugh was re-elected a member of the Auditing Committee for a three-year term, and Juan T. Trippe was elected a member of the Auditing Committee to serve for three years. William I. Myers was elected a member of the Nominating Committee for a period of three years, succeeding Robert A. Lovett. Lindsay Bradford was re-elected a member of the Retirement Committee for a three-year term. The following were elected for one-year terms: Lindsay Bradford as Chairman of the Finance Committee and as Chairman of the Retirement Committee, and Keith S. McHugh as Chairman of the Auditing Committee and as Chairman of the Nominating Committee.

REPORT OF THE EXECUTIVE COMMITTEE

For the Year Ended June 30, 1955

To the Trustees of the Carnegie Institution of Washington:

Gentlemen: In accordance with the provisions of the By-Laws, the Executive Committee submits this report to the annual meeting of the Board of Trustees.

During the fiscal year ended June 30, 1955, the Executive Committee held four meetings, printed reports of which have been mailed to each Trustee and constitute a part of this report.

The detailed record of the activities of the Institution is presented in the reports from the Departments, which are contained in the Year Book. The estimate of expenditures for the calendar year 1956 contained in the report of the President has been considered and approved by the Executive Committee, and the Committee has also provisionally approved and recommends to the Board the proposed budget based thereon.

The Board of Trustees, at its meeting of December 10, 1954, appointed the firm of Haskins & Sells to audit the accounts of the Institution for the fiscal year ending June 30, 1955. The report of the Auditor, including a balance sheet showing assets and liabilities of the Institution on June 30, 1955, together with supporting statements and schedules, is submitted as a part of the report of the Executive Committee.

One vacancy exists in the membership of the Board of Trustees, resulting from the resignation of Roswell Miller in July 1955.

The term of Mr. Prentis as a member of the Executive Committee will end at the annual meeting in December, and another vacancy will exist in the Executive Committee when Dr. Haskins becomes an ex officio member on becoming President of the Institution on January 1, 1956. Terms of Mr. McHugh, Chairman, and Mr. Henry as members of the Auditing Committee, and of Mr. Bradford, Chairman, as a member of the Retirement Committee will end at the annual meeting. The term of Mr. Lovett as a member of the Nominating Committee will also end at the annual meeting.

Barklie Henry, *Chairman*

October 20, 1955

HASKINS & SELLS
CERTIFIED PUBLIC ACCOUNTANTS

500 EQUITABLE BUILDING
BALTIMORE 2

ACCOUNTANTS' CERTIFICATE

To the Board of Trustees of Carnegie Institution of Washington:

We have examined the balance sheet of Carnegie Institution of Washington as of June 30, 1955 and the related summaries of current income and expenditures, current funds surplus, current restricted gifts and grants, changes in endowment and other special funds, and changes in investment in real estate and equipment for the year then ended (Exhibits A to F, inclusive). Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

In our opinion, the accompanying balance sheet and above described summaries (Exhibits A to F, inclusive) present fairly the financial position of the Institution at June 30, 1955 and the results of its operations for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

HASKINS & SELLS

August 16, 1955

BALANCE SHEET, JUNE 30, 1955

ASSETS

Current Funds:			
Cash		$732,800.58	
Advances:			
Departmental Research Operations		11,140.66	
Other		549.77	
Accounts receivable		554.87	
Deferred charges		19,063.68	
Due from Endowment and Other Special Funds		96,533.24	$860,642.80
Endowment and Other Special Funds:			
Cash		$50,506.11	
Securities (valuation based on market quotations at June 30, 1955—$69,450,440)—Schedule 1:			
Bonds	$30,692,965.35		
Preferred stocks	3,784,869.57		
Common stocks	15,313,451.40	49,791,286.32	49,841,792.43
Plant Funds:			
Investment in real estate and equipment—Exhibit F			5,174,924.83
Total			$55,877,360.06

LIABILITIES

Current Funds:			
Accounts payable		$1,665.87	
Reserve for accounts receivable		554.87	
Current Funds Surplus—Exhibit C:			
Appropriated unexpended balances	$489,819.03		
General Contingent Fund	296,340.36	786,159.39	
Unexpended balance of restricted gifts and grants—Exhibit D		72,262.67	$860,642.80
Endowment and Other Special Funds:			
Due to Current Funds		$96,533.24	
Principal of Funds—Exhibit E:			
Capital funds	$46,474,470.25		
Special funds	3,270,788.94	49,745,259.19	49,841,792.43
Plant Funds:			
Bequests, gifts, and income invested in plant		$5,131,424.83	
Harriman Fund—donated land		5,500.00	
Hale Fund—Solar Laboratory		38,000.00	5,174,924.83
Total			$55,877,360.06

NOTE: The value of the Institution's stock of publications and the related reserve for valuation of books have been omitted from the Institution's Financial Statement at June 30, 1955.

EXHIBIT B

SUMMARY OF CURRENT INCOME AND EXPENDITURES FOR THE YEAR ENDED JUNE 30, 1955

Current Income:		
Investment income:		
Interest and dividends on securities	$2,111,197.96	
Less: Amortization of bond premiums	17,751.08	$2,093,446.88
Market value of stock dividend		8,300.00
Total—Schedule 1		$2,101,746.88
Less: Income added to Special Funds (Exhibit E)—Schedule 1		1,735.47
Remainder—Income available for current purposes		$2,100,011.41
Other income:		
Sales of publications	$5,671.75	
Dormitory and mess hall	6,701.57	
Miscellaneous	1,750.25	14,123.57
Restricted gifts and grants utilized for current purposes—Exhibit D		43,281.76
Total Current Income		$2,157,416.74
Current Expenditures (including expenditures against appropriations of prior years)—Schedule 4:		
Administration	$245,422.82	
Departmental Research Operations	1,367,037.97	
General Publications	37,841.33	
Research Projects, Fellowships, Grants, etc.	69,492.64	
Pension Fund—annuity and insurance	127,309.69	
Retirement Plan Contributions	211,869.15	
	$2,058,973.60	
Gifts and grants—Exhibit D	43,281.76	
Total Current Expenditures		2,102,255.36
Excess of Current Income over Current Expenditures—Exhibit C		$55,161.38 *

* Summarized as follows:

Current investment income in excess of Trustees' authorized appropriations during the fiscal year, credited to General Reserve Fund—Exhibit E	$193,711.15	
Market value of stock dividend credited to Special Income Reserve—Exhibit E	8,300.00	
Transfer of unexpended current appropriations to General Contingent Fund—Schedule 4	39,759.50	
Reserved from this year's appropriations for current liabilities and commitments—Schedule 4	154,792.64	
Total	$396,563.29	
Less: Amount included in current expenditures, applicable to allotments and unexpended balances from prior years' appropriations—Schedule 4	341,401.91	$55,161.38

EXHIBIT C

SUMMARY OF CURRENT FUNDS SURPLUS
FOR THE YEAR ENDED JUNE 30, 1955

Balance, July 1, 1954		$928,812.82
Additions:		
Excess of current income over current expenditures—Exhibit B	$55,161.38	
Transfer from Special Funds—Exhibit E:		
General Reserve Fund—to cover miscellaneous expenditures in connection with the building program at Cold Spring Harbor	3,996.34	
Harriet H. Mayor Relief Fund	200.00	59,357.72
Total		$988,170.54
Deductions:		
Transfer to Special Funds—Exhibit E:		
General Reserve Fund, representing excess of investment income over Trustees' appropriations for current purposes	$193,711.15	
Special Income Reserve, representing market value of stock dividend received during year	8,300.00	202,011.15
Balance, June 30, 1955, per Schedule 3		$786,159.39

EXHIBIT D

SUMMARY OF CURRENT RESTRICTED GIFTS AND GRANTS FOR THE YEAR ENDED JUNE 30, 1955

	Unexpended Balance July 1, 1954	Additions—Gifts and Grants Received	Deductions—Expenditures (Schedule 4)	Unexpended Balance June 30, 1955
Departmental Research Operations:				
Department of Genetics:				
American Cancer Society No. EG 21	$1,826.24	$7,400.00	$6,909.59	$2,316.65
American Cancer Society No. INSP-72	116.72	....	116.72	....
U. S. Public Health Service No. RG-149 C	3,850.13	9,190.86	9,376.18	3,664.81
U. S. Public Health Service No. C-2158 C	2,899.17	10,537.74	11,313.14	2,123.77
U. S. Public Health Service - Hartman	....	500.00	500.00	....
National Foundation for Infantile Paralysis	5.00	1,100.00	1,091.43	13.57
Department of Terrestrial Magnetism:				
National Science Foundation	....	18,800.00	1,451.39	17,348.61
Department of Embryology:				
U. S. Public Health Service - Greenwald	....	500.00	500.00	....
Research Projects, Fellowships, etc.:				
Carnegie Corporation of New York:				
Biology:				
Point Lobos, California	2,245.32	137.75	....	2,383.07
Geology:				
Tilley, C. E.	620.63	....	....	620.63
Physiology:				
Russell, G. Oscar	1,222.44	....	....	1,222.44
Terrestrial Magnetism:				
Clews, C. J. Birkett	2,401.69	....	191.95	2,209.74
Jeffery, Peter	....	5,000.00	2,372.50	2,627.50
Magnetic polarization of the earth	2,391.99	....	1,547.32	844.67
Telescope image converter	44,798.75	....	7,911.54	36,887.21
Total	$62,378.08	$53,166.35	$43,281.76	$72,262.67

EXHIBIT E

SUMMARY OF CHANGES IN ENDOWMENT AND OTHER SPECIAL FUNDS FOR THE YEAR ENDED JUNE 30, 1955

		Additions			Deductions			
						Expenditures		
	Balance July 1, 1954	Gifts, Sale of Property and Misc.	Income from Investments Added to Funds (Exhibit B)	Net Realized Gain on Investments (Schedule 2)	Transfer to Current Funds Surplus (Exhibit C)	Plant (Exhibit F)	Other	Balance June 30, 1955
Capital Funds:								
Endowment Fund	$32,000,000.00	....	....	....	....	....	....	$32,000,000.00
Capital Reserve Fund	10,075,912.56	....	....	$4,278,028.84	....	....	....	14,353,941.40
Colburn Fund	103,310.80	....	....	....	....	....	....	103,310.80
Harkavy Fund	3,058.80	$1,992.25	....	....	....	....	....	5,051.05
Harriman Fund	....	6,850.75	....	....	....	$6,850.75	....	....
Teeple Fund	10,888.42	....	....	....	....	....	....	10,888.42
Van Gelder Fund	1,278.58	....	....	....	....	....	....	1,278.58
Special Funds:								
Bickel Fund	11,062.27	....	$490.74	....	....	....	....	11,553.01
General Reserve Fund *	2,746,859.57	5,512.28	193,711.15	....	$3,996.34	-3,093.91	....	2,945,180.57
George E. Hale Relief Fund	4,164.44	....	183.02	....	....	....	....	4,347.46
Harkavy Fund—Income	825.64	....	224.07	....	....	....	....	1,049.71
Harriet H. Mayor Relief Fund	7,399.47	....	....	....	200.00	....	$1,132.80	6,066.67
Special Income Reserve	212,321.89	....	8,300.00	....	....	....	....	220,621.89
Special Purpose Fund	52,250.00	10,000.00	....	....	....	....	....	62,250.00
Woloff Fund	18,881.99	....	837.64	....	....	....	....	19,719.63
Total	$45,248,214.43	$24,355.28	$203,746.62	$4,278,028.84	$4,196.34	$3,756.84	$1,132.80	$49,745,259.19

* To cover the balance of the cost of completing the building program at Cold Spring Harbor, in excess of the Harriman and Lecture Hall Funds available for this purpose, the Trustees at their December 14, 1951 meeting appropriated an amount not to exceed $350,000.00 from the General Reserve Fund. $287,962.01 has been charged against this authorization.

EXHIBIT F

SUMMARY OF CHANGES IN INVESTMENT IN REAL ESTATE AND EQUIPMENT FOR THE YEAR ENDED JUNE 30, 1955

	Balance July 1, 1954	Additions (see Note A)	Deductions	Balance June 30, 1955	Classification of June 30, 1955 Balance: Buildings and Grounds	Laboratory Apparatus	Library	Operating Equipment
Departments of Research:								
Department of Plant Biology Stanford, California	$156,291.61	$1,621.59	$24.20	$157,889.00	$71,897.68	$42,805.88	$27,033.88	$16,151.56
Department of Genetics Long Island, New York	1,196,074.67	10,152.22	33,610.54 B	1,172,616.35	985,150.41	79,534.31	74,173.28	33,758.35
Geophysical Laboratory Washington, D. C.	455,260.61	7,162.14	4,125.90	458,296.85	170,383.79	195,653.65	45,016.81	47,242.60
Department of Archaeology Cambridge, Massachusetts	20,049.01	128.96	1,853.84	18,324.13	....	....	1,261.67	17,062.46
Mount Wilson Observatory Pasadena, California	1,659,913.00	6,758.45	1,612.29	1,665,059.16	275,827.70	1,241,625.39	80,422.65	67,183.42
Department of Terrestrial Magnetism Washington, D. C.	802,248.82	9,669.97	2,353.14	809,565.65	401,418.69	288,011.04	45,501.46	74,634.46
Department of Embryology Baltimore, Maryland	55,808.66	1,852.80	....	57,661.46	....	43,258.28	9,352.93	5,050.25
Total Departments of Research	$4,345,646.38	$37,346.13	$43,579.91	$4,339,412.60	$1,904,678.27	$1,890,888.55	$282,762.68	$261,083.10
Office of Administration Washington, D. C.	832,918.28	5,809.45	3,215.50	835,512.23	797,632.96	....	....	37,879.27
Total	$5,178,564.66	$43,155.58	$46,795.41	$5,174,924.83	$2,702,311.23	$1,890,888.55	$282,762.68	$298,962.37

Notes:

A. Additions during year provided from following:

Current expenditures for equipment—Schedule 4	$37,863.59
Expenditures charged to Endowment and Other Special Funds for building program at Cold Spring Harbor—Exhibit E	3,756.84
Cost of constructed equipment capitalized:	
Mount Wilson Observatory	1,535.15
Total, as above	$43,155.58

B. Includes disposals of buildings and grounds in connection with building program at Cold Spring Harbor.

SCHEDULE 1 ENDOWMENT AND OTHER SPECIAL FUNDS INVESTMENTS AS OF JUNE 30, 1955 AND INCOME THEREFROM DURING THE YEAR

	Book Value	Market Value	Per Cent of Total Investments: Book Value	Per Cent of Total Investments: Market Value	Income Received
Bonds:					
United States Government	$14,836,327.74	$14,618,889	29.77%	21.03%	$229,805.64
Foreign and International Bank	990,036.56	990,799	1.99%	1.43%	36,096.39
Public Utility	2,918,421.31	2,843,265	5.86%	4.09%	89,149.82
Communication	1,326,360.88	1,292,500	2.66%	1.86%	33,485.69
Railroad	477,563.46	513,320	.96%	.74%	23,994.29
Railroad Equipment Trust	1,075,747.63	1,078,904	2.16%	1.55%	23,708.16
Industrial and Miscellaneous	9,068,507.77	9,023,166	18.19%	12.98%	226,294.87
Total bonds	$30,692,965.35	$30,360,843	61.59%	43.68%	$662,534.86 *
Stocks:					
Preferred	$3,784,869.57	$3,819,164	7.59%	5.50%	$154,849.95
Common	15,313,451.40	35,270,433	30.72%	50.75%	1,284,362.07 †
Total stocks	$19,098,320.97	$39,089,597	38.31%	56.25%	$1,439,212.02
Cash	$50,506.11	$50,506	.10%	.07%	....
Total	$49,841,792.43	$69,500,946	100.00%	100.00%	$2,101,746.88 ‡

* After deducting bond premium amortization of $17,751.08.

† Includes $8,300.00 representing market value of a stock dividend received.

‡ Income received allocated to Endowment and Other Special Funds as follows:

Funds, the income from which may be used for current general purposes—Exhibit B		$2,100,011.41
Funds, the income from which is restricted to specific purposes—Exhibit E:		
Bickel Fund	$490.74	
George E. Hale Relief Fund	183.02	
Harkavy Fund	224.07	
Woloff Fund	837.64	1,735.47
Total		$2,101,746.88

SCHEDULE OF SECURITIES

Principal amount	Description	Maturity	Book value	Approximate market value
	United States Government Bonds			
$1,335,000	U. S. of America Treasury Bills	8-18-1955	$1,330,260.75	$1,332,744
225,000	U. S. of America Treasury Notes Series "A" $1\frac{7}{8}$s	1959	224,929.69	220,359
675,000	U. S. of America Treasury Notes Series "C" 2s	1957	672,152.35	671,625
2,350,000	U. S. of America Treasury $2\frac{1}{4}$s	1962-59	2,374,012.35 *	2,285,375
1,500,000	U. S. of America Treasury $2\frac{1}{2}$s	1958	1,498,089.77	1,503,281
1,250,000	U. S. of America Treasury $2\frac{1}{2}$s	1961	1,250,000.00	1,231,641
3,588,000	U. S. of America Treasury $2\frac{1}{2}$s	1963	3,593,132.83	3,512,876
800,000	U. S. of America Treasury $2\frac{3}{4}$s	1961	800,000.00	800,250
1,000,000	U. S. of America Treasury Series "B" $2\frac{3}{4}$s	1980-75	991,093.75	950,000
1,000,000	U. S. of America Treasury 3s	1995	1,002,656.25	1,002,188
400,000	U. S. of America Treasury $3\frac{1}{4}$s	1983-78	400,000.00	423,750
100,000	U. S. of America Savings Series "G" $2\frac{1}{2}$s	1956	100,000.00	99,200
100,000	U. S. of America Savings Series "G" $2\frac{1}{2}$s	1957	100,000.00	98,200
100,000	U. S. of America Savings Series "G" $2\frac{1}{2}$s	1958	100,000.00	97,600
100,000	U. S. of America Savings Series "G" $2\frac{1}{2}$s	1959	100,000.00	97,000
100,000	U. S. of America Savings Series "G" $2\frac{1}{2}$s	1960	100,000.00	95,800
200,000	U. S. of America Savings Series "K" 2.76s	1966	200,000.00	197,000
$14,823,000	Total U. S. Government		$14,836,327.74	$14,618,889
	Foreign and International Bank Bonds			
$267,000	Aluminum Company of Canada, Ltd., S. F. Deb. $3\frac{7}{8}$s Guar.	1970	$270,304.21 *	$281,018
100,000	Canadian National Ry. Co., $4\frac{1}{2}$s Guar.	1957	112,000.00	106,375
125,000	International Bank for Reconstruction and Development, 3s	1976	125,000.00	122,500
125,000	International Bank for Reconstruction and Development, $3\frac{3}{8}$s	1975	123,125.00	127,656
150,000	Noranda Mines Ltd., S. F. Deb. $4\frac{3}{4}$s	1968	153,847.35 *	158,250
200,000	Shawinigan Water & Power Co., 1st Mtg. & Coll. Tr. S. F. Series "M" 3s	1971	205,760.00 *	195,000
$967,000	Total Foreign and International Bank		$990,036.56	$990,799
	Public Utility Bonds			
$125,000	Columbia Gas System, Inc., Series "B" 3s	1975	$127,722.77 *	$121,563
237,000	Columbus & Southern Ohio Electric Co., 1st Mtg. $3\frac{1}{4}$s	1970	246,716.44 *	242,333
300,000	Consolidated Natural Gas Co., Deb. $2\frac{3}{4}$s	1968	300,555.04 *	294,000
200,000	Minnesota Power & Light Co., 1st Mtg. $3\frac{1}{8}$s	1975	203,317.85 *	194,000
100,000	Ohio Power Co., 1st Mtg. $3\frac{1}{4}$s	1968	101,500.00	102,250
200,000	Pacific Gas and Electric Co., 1st & Ref. Mtg. Series "X" $3\frac{1}{8}$s	1984	201,691.66 *	199,250
300,000	Pacific Gas and Electric Co., 1st & Ref. Mtg. Series "Y" $3\frac{3}{8}$s	1987	307,180.51 *	312,000
200,000	Panhandle Eastern Pipe Line Co., Serial Deb. $2\frac{3}{4}$s	1961-62	201,240.27 *	198,030
92,000	Panhandle Eastern Pipe Line Co., S. F. Deb. $3\frac{1}{4}$s	1973	93,194.72 *	93,380
50,000	Philadelphia Electric Co., 1st & Ref. Mtg. $2\frac{7}{8}$s	1978	49,687.50	48,250
207,000	Philadelphia Electric Power Co., 1st Mtg. $2\frac{5}{8}$s Guar.	1975	210,488.92 *	197,944
200,000	Public Service Co. of Indiana, Inc., 1st Mtg. Series "F" $3\frac{1}{8}$s	1975	203,371.43 *	201,000
210,000	Tennessee Gas Transmission Co., 1st Mtg. Pipe Line $2\frac{3}{4}$s	1966	211,732.50 *	200,550
191,000	Tennessee Gas Transmission Co., 1st Mtg. Pipe Line 3s	1969	195,021.70 *	184,315
265,000	United Gas Corp., 1st Mtg. & Coll. Tr. $2\frac{3}{4}$s	1967	265,000.00 *	254,400
$2,877,000	Total Public Utility		$2,918,421.31	$2,843,265

* After deduction for amortization of premiums on bonds purchased subsequent to January 1, 1940.

SCHEDULE OF SECURITIES—Continued

Principal amount	Description	Maturity	Book value	Approximate market value
	Communication Bonds			
$150,000	American Telephone & Telegraph Co., Deb. $2\frac{3}{4}$s	1975	$151,743.75 *	$141,000
350,000	American Telephone & Telegraph Co., Deb. $3\frac{1}{4}$s	1984	362,549.08 *	353,500
200,000	Mountain States Telephone & Telegraph Co., Deb. $3\frac{1}{8}$s	1978	201,260.00 *	198,000
100,000	New York Telephone Co., Ref. Mtg. Series "E" $3\frac{1}{8}$s ..	1978	101,084.83 *	100,000
200,000	Pacific Telephone & Telegraph Co., Deb. $3\frac{1}{4}$s	1978	203,973.22 *	203,750
300,000	Southwestern Bell Telephone Co., Deb. $3\frac{1}{8}$s	1983	305,750.00 *	296,250
$1,300,000	Total Communication		$1,326,360.88	$1,292,500
	Railroad Bonds			
$100,000	Chesapeake & Ohio Ry. Co., Gen. Mtg. $4\frac{1}{2}$s..............	1992	$99,464.29	$124,125
271,000	Fort Worth & Denver Rwy. Co., 1st Mtg. $4\frac{3}{8}$s Guar. ..	1982	273,436.67 *	283,195
100,000	Pennsylvania R. R. Co., Cons. Mtg. $4\frac{1}{2}$s	1960	104,662.50	106,000
$471,000	Total Railroad		$477,563.46	$513,320
	Railroad Equipment Trust Bonds			
$150,000	Chesapeake & Ohio Ry. Co., Eq. Tr. 2s Guar.	1956-58	$146,340.34	$148,560
300,000	Chicago Burlington & Quincy R. R. Co., Eq. Tr. $2\frac{1}{4}$s Guar.	1958-63	292,507.12	291,805
100,000	Great Northern Railway Co., Eq. Tr. 2s Guar.	1960-61	98,538.91	97,055
150,000	Pennsylvania R. R. Co., Eq. Tr. Series "S" $2\frac{3}{8}$s Guar.	1958-62	146,358.96	145,209
100,000	Southern Pacific Co., Eq. Tr. Series "CC" $2\frac{1}{8}$s Guar.	1956 & 59	99,822.51 *	98,855
150,000	Southern Pacific Co., Eq. Tr. Series "X" $2\frac{1}{8}$s Guar. .	1956-58	146,251.10	148,710
150,000	Southern Railway Co., Eq. Tr. Series "NN" $2\frac{1}{8}$s Guar.	1956-58	145,928.69	148,710
$1,100,000	Total Railroad Equipment Trust		$1,075,747.63	$1,078,904
	Industrial and Miscellaneous Bonds			
$200,000	Allied Chemical and Dye Corp., Deb. $3\frac{1}{2}$s	1978	$198,000.00	$207,500
200,000	Aluminum Company of America, S. F. $3\frac{1}{8}$s	1964	200,000.00	201,000
100,000	Aluminum Company of America, S. F. Deb. 3s	1979	100,000.00	99,625
187,000	American Tobacco Co., Deb. 3s	1969	188,927.67 *	186,299
500,000	Bethlehem Steel Corp., Conv. Deb. $3\frac{1}{4}$s	1980	551,611.86	610,000
234,000	Bristol Myers Co., Deb. 3s	1968	234,745.50 *	229,905
300,000	C. I. T. Financial Corp., Deb. $2\frac{5}{8}$s	1959	300,000.00 *	294,750
400,000	Continental Oil Company, S. F. Deb. 3s	1984	404,913.80 *	394,000
150,000	Dow Chemical Co., Deb. 2.35s	1961	150,375.01 *	144,000
130,000	Dow Chemical Co., Conv. Sub. Deb. 3s	1982	131,792.48 *	158,600
153,000	Food Machinery Corp., S. F. Deb. $2\frac{1}{2}$s	1962	152,308.98	148,410
250,000	General Motors Acceptance Corp., Deb. 3s	1960	250,000.00	250,000
200,000	General Motors Acceptance Corp., Deb. $3\frac{1}{2}$s	1972	205,250.00	206,750
180,000	General Motors Acceptance Corp., Deb. 4s	1958	180,000.00	183,825
500,000	General Motors Corporation, Deb. $3\frac{1}{4}$s	1979	502,375.00 *	513,750
275,000	Goodrich (B. F.) Company, 1st Mtg. $2\frac{3}{4}$s	1965	275,651.37 *	272,594
243,000	P. Lorillard Co., Deb. 3s	1963	246,925.88 *	242,393
295,000	National Dairy Products Corp., Deb. $2\frac{3}{4}$s	1970	298,062.80 *	289,100
488,000	Phillips Petroleum Co., S. F. Deb. $2\frac{3}{4}$s	1964	491,911.77 *	479,460
337,000	Phillips Petroleum Co., Conv. S. F. Deb. 3.70s	1983	364,699.58 *	392,605
125,000	Pittsburgh Plate Glass Co., S. F. Deb. 3s	1967	125,000.00	125,000
150,000	Quaker Oats Co., Deb. $2\frac{5}{8}$s	1964	148,922.50	147,000
300,000	Seagram (Joseph E.) & Sons, Inc., Deb. $2\frac{1}{2}$s	1966	298,500.00	283,500
300,000	Service Pipe Line Co., S. F. Deb. 3.20s	1982	300,000.00	303,000
500,000	Shell Union Oil Corp., Deb. $2\frac{1}{2}$s	1971	503,207.93 *	470,000
500,000	Socony Mobil Oil Co., Inc., Deb. $2\frac{1}{2}$s	1976	489,528.75	462,500
100,000	Standard Oil Company (Ind.), Conv. Deb. $3\frac{1}{8}$s	1982	101,189.60 *	119,500
300,000	Swift & Co., Deb. $2\frac{5}{8}$s	1972	301,201.41 *	283,500
500,000	Texas Corporation, Deb. 3s	1965	516,073.61 *	503,750
346,000	Union Oil Company of California, Deb. $2\frac{3}{4}$s	1970	354,149.71 *	337,350
100,000	Union Oil Company of California, Conv. Deb. Sub. 3s .	1975	100,000.00	108,500
400,000	Westinghouse Electric Corporation, Deb. $2\frac{5}{8}$s	1971	403,182.56 *	375,000
$8,943,000	Total Industrial and Miscellaneous		$9,068,507.77	$9,023,166
$30,481,000	Bonds—Funds Invested		$30,692,965.35	$30,360,843

* After deduction for amortization of premiums on bonds purchased subsequent to January 1, 1940.

Number of shares	Description	Book value	Approximate market value
	Preferred Stocks		
400	Air Reduction Company, Inc., 4.50% Cum. Conv. Pref. 51 Series.....	$41,195.04	$53,000
1,500	Appalachian Electric Power Co., 4½ Cum. Pref.	159,000.00	163,875
2,000	Armstrong Cork Co., $3.75 Cum. Pref.	205,500.00	200,000
1,500	Bethlehem Steel Corp., 7% Cum. Pref.	183,637.50	251,250
500	Case (J. I.) Co., 7% Cum. Pref.	62,225.00	62,250
600	Cleveland Electric Illuminating Co., $4.50 Cum. Pref.	68,112.25	65,700
1,900	Consolidated Edison Co. of N. Y., Inc. $5.00 Cum. Pref.	202,815.50	210,900
1,125	Continental Can Co., Inc., $3.75 Cum. Pref.	115,312.50	114,188
600	Corn Products Refining Co., 7% Cum. Pref.	110,335.18	107,250
2,075	duPont (E. I.) de Nemours & Co., $4.50 Cum. Pref.	235,401.89	250,556
1,000	El Paso Natural Gas Co., 4.10% Cum. Pref.	111,442.21	99,000
1,500	General Foods Corp., $3.50 Cum. Pref.	150,750.00	147,375
1,500	General Motors Corp., $5.00 Cum. Pref.	187,937.50	189,375
1,000	General Shoe Corporation, $3.50 Cum. Pref. Series "A"	102,250.00	90,000
1,000	Grant (W. T.) Co., 3¾% Cum. Pref.	100,447.91	96,000
300	Merck & Co., Inc., $4.00 Cum. Conv. 2nd Pref.	31,200.00	32,850
800	National Distillers Products Corp., 4¼% Cum. Conv. Pref.	80,000.00	80,000
2,000	Niagara Mohawk Power Corp., 3.60% Cum. Pref.	207,990.00	178,000
1,300	Ohio Power Co., 4½% Cum. Pref.	144,630.02	142,025
1,500	Pacific Telephone and Telegraph Co., 6% Cum. Pref.	235,220.75	222,750
1,000	Panhandle Eastern Pipe Line Co., 4% Cum. Pref.	104,166.68	101,500
900	Pillsbury Mills, Inc., $4.00 Cum. Pref.	96,949.80	90,675
2,000	Reynolds (R. J.) Tobacco Co., 3.60% Cum. Pref.	199,683.75	171,000
690	Sherwin-Williams Co., 4% Cum. Pref.	76,049.65	74,520
1,200	Standard Oil Co. of Ohio, 3¾% Cum. Pref. Series "A"	129,208.87	120,600
3,100	U. S. Steel Corp., 7% Cum. Pref.	443,407.57	504,525
32,990	Total Preferred Stocks	$3,784,869.57	$3,819,164
	Common Stocks		
2,000	Allied Chemical & Dye Corporation	$96,175.97	$239,500
5,830	Aluminium Limited	247,080.22	613,608
5,000	Aluminum Company of America	208,437.50	347,500
10,250	American Gas and Electric Company	214,294.48	458,688
5,000	American Telephone & Telegraph Co.	737,124.15	914,375
8,000	Armco Steel Corporation	300,711.62	359,000
14,100	Armstrong Cork Company	231,516.80	437,100
2,800	Atchison, Topeka and Santa Fe Rwy. Co.	232,758.69	413,000
4,000	Bethlehem Steel Corporation	297,908.79	569,500
3,500	C. I. T. Financial Corporation	70,638.96	165,375
5,000	Carrier Corporation	202,162.77	272,500
4,000	Caterpillar Tractor Company	96,913.60	225,000
2,500	Chase Manhattan Bank of New York	71,361.04	127,500
60	Christiana Securities Co.	356,143.00	924,000
4,000	Consumers Power Co.	145,974.04	189,500
2,300	Continental Can Company, Inc.	106,779.99	186,875
3,000	Continental Insurance Co.	113,787.87	303,750
12,200	Continental Oil Co. of Delaware	239,598.64	1,091,900
2,500	Corning Glass Works	59,631.83	177,500
6,100	Delaware Power & Light Company	128,803.87	218,075
4,200	Dow Chemical Company	154,131.30	242,550
3,800	duPont (E. I.) de Nemours & Co.	155,091.50	873,050
8,379	Eastman Kodak Company	209,388.59	675,557
4,344	Fireman's Fund Insurance Co.	128,858.78	327,972
5,700	First National City Bank of New York	279,775.25	346,988
6,000	Florida Power & Light Company	148,863.69	225,000
34,000	General Electric Company	701,178.76	1,806,250
4,000	General Foods Corporation	167,302.84	330,000
8,300	General Motors Corporation	460,248.37	905,738
8,300	Goodrich (B. F.) Company	243,387.19	561,288
11,000	Gulf Oil Corp.	218,016.33	951,500
10,625	Gulf States Utilities Co.	223,782.34	363,906
2,000	Halliburton Oil Well Cementing Company	47,813.65	119,500

(Concluded on following page)

Number of shares	Description	Book value	Approximate market value
	Common Stocks—Concluded		
1,250	Hartford Fire Insurance Company	$53,952.55	$218,750
2,500	Illinois Power Co.	97,697.35	132,500
8,600	Insurance Company of North America	219,767.73	1,066,400
2,700	International Business Machines Corp.	129,338.57	1,120,500
5,000	International Nickel Co. of Canada, Ltd.	185,533.15	358,125
4,000	International Paper Company	189,122.23	444,000
2,800	Johns-Manville Corp.	146,694.33	236,600
3,900	Kennecott Copper Corporation	199,127.15	460,200
10,000	Kimberly-Clark Corporation	227,813.88	550,000
4,700	Lehigh Portland Cement Company	278,271.46	332,525
1,280	Mellon National Bank and Trust Company	67,193.07	124,800
5,000	Mercantile Stores Company, Inc.	108,875.28	140,000
5,000	Merck & Co., Inc.	93,798.41	112,500
7,000	Middle South Utilities, Inc.	168,660.65	221,375
9,000	Minneapolis-Honeywell Regulator Co.	103,971.05	567,000
5,000	Monsanto Chemical Co.	327,552.73	720,000
3	Northern Natural Gas Company	129.00	127
3,300	Ohio Edison Co.	105,150.00	159,225
7,000	Penney (J. C.) Co.	248,413.74	661,500
1,000	Peoples Gas Light and Coke Company	106,350.00	159,000
2,400	Phelps Dodge Corporation	71,057.69	132,000
3,800	Pittsburgh Plate Glass Co.	122,609.63	302,100
4,200	Procter & Gamble Co.	177,227.28	408,450
10,000	Puget Sound Power and Light Company	367,935.80	383,750
5,600	Scott Paper Co.	74,258.77	414,400
7,800	Seaboard Oil Co.	229,104.22	432,900
7,000	Sears, Roebuck & Co.	159,816.65	656,250
11,220	Shell Oil Company	413,016.26	706,860
4,000	Sherwin-Williams Co.	245,189.82	432,000
9,900	Socony Mobil Oil Company, Inc.	300,464.13	595,238
5,800	Southern California Edison Company	208,276.33	290,725
4,500	Southern Railway Co.	218,508.81	432,000
8,000	Standard Oil Co. of Indiana	145,038.34	418,000
11,002	Standard Oil Co. of New Jersey	266,540.74	1,413,757
5,200	Texas Company	137,243.60	530,400
2,800	Texas Utilities Company	154,487.73	207,200
4,500	Union Carbide & Carbon Corp.	141,068.15	459,000
8,000	Union Electric Company of Missouri	140,635.05	236,000
1,000	Union Pacific R. R. Co.	114,547.42	170,000
8,855	United Gas Corp.	144,892.59	286,681
2,600	United States Gypsum Co.	235,570.53	729,300
19,600	United States Steel Corporation	448,008.56	1,065,750
6,000	Virginia Electric and Power Co.	130,447.67	229,500
8,000	West Virginia Pulp and Paper Co.	226,533.72	377,000
1,700	Weyerhaeuser Timber Company	87,917.16	212,500
465,298	Total Common Stocks	$15,313,451.40	$35,270,433
	Common and Preferred Stocks—Funds Invested	$19,098,320.97	$39,089,597
	Aggregate Investments (Bonds and Stocks)	$49,791,286.32	$69,450,440

SUMMARY OF SECURITY TRANSATIONS JULY 1, 1954 TO JUNE 30, 1955

Cash awaiting investment—July 1, 1954				$57,149.46
	Sales and Redemptions			
	Gain	Loss	Book Value	
Bonds	$81,905.08	....	$1,464,737.60	
Preferred Stocks	....	$1,080.42	17,380.42	
Common Stocks	4,182,560.24	....	4,154,759.42	
Sale of Stock Rights	14,643.94	....	....	
	$4,279,109.26	$1,080.42	$5,636,877.44	
Net Gain—To Exhibit E	....	4,278,028.84	4,278,028.84	9,914,906.28
	$4,279,109.26	$4,279,109.26		
Income applied to amortization of bond premiums				17,751.08
Market value of stock dividend				8,300.00
Total				$9,998,106.82
	Acquisitions			
Bonds			$7,307,314.04	
Common Stocks			2,640,286.67	9,947,600.71
Cash awaiting investment—June 30, 1955				$50,506.11

SCHEDULE 3

SUMMARY OF CHANGES IN CURRENT FUNDS SURPLUS ACCOUNTS AND RESTRICTED GIFTS AND GRANTS FOR THE YEAR ENDED JUNE 30, 1955

		Additions				Deductions		
	Balance July 1, 1954	Trustees' Appropriations (Schedule 4)	Allotments and Transfers—Net	Other Credits	Transfer From Special Funds	Expenditures (Schedule 4)	Transfers to General Contingent Fund (see Note)	Balance June 30, 1955
Current Funds Surplus:								
Appropriated:								
Departmental Research Operations:								
Department of Plant Biology	$5,494.85	$101,800.00	$8,513.00	...	...	$88,817.63	$15,613.50	$11,376.72
Department of Genetics	3,559.86	175,814.00	7,900.00	$1,050.00	$3,996.34	186,106.44	1,219.46	4,994.30
Dormitory and Mess Hall	1,972.59	1,200.00	...	6,701.57	...	7,607.92	...	2,266.24
Geophysical Laboratory	21,935.97	202,850.00	58,073.85	...	...	243,123.88	3,323.56	36,412.38
Department of Archaeology	3,866.30	101,184.00	...	...	...	91,707.76	10,430.09	2,912.45
Mount Wilson Observatory	15,463.40	284,525.00	3,600.00	...	...	272,842.45	6,375.13	24,370.82
Department of Terrestrial Magnetism	23,877.33	313,900.00	33,911.55	350.00	...	342,764.75	109.92	29,164.21
Department of Embryology	2,989.81	138,520.00	3,760.00	...	200.00	134,067.14	2,949.14	8,453.53
Total Departmental Research Operations	$79,160.11	$1,319,793.00	$115,758.40	$8,101.57	$4,196.34	$1,367,037.97	$40,020.80	$119,950.65
Administration	5,985.41	218,075.00	30,820.77	350.25	...	245,422.82	165.49	9,643.12
General Operations	58,360.66	149,500.00	−139,761.39	...	−867.74	...	...	67,231.53
General Publications	65,032.93	30,000.00	−1,500.00	5,671.75	...	37,841.33	...	61,363.35
Research Projects, Fellowships, etc.	61,000.66	...	103,110.53	...	...	69,492.64	2,000.00	92,618.55
Pension Fund	140,754.99	92,062.55	32,722.46	...	...	127,309.69	...	138,230.31
Retirement Plan Contributions	...	89,437.45	123,213.22	...	...	211,869.15	...	781.52
Total	$410,294.76	$1,898,868.00	$264,363.99	$14,123.57	$3,328.60	$2,058,973.60	$42,186.29	$489,819.03
Unallotted:								
General Contingent Fund	518,518,06	...	−264,363.99	...	...	...	−42,186.29	296,340.36
Total Current Funds Surplus—Exhibit C	$928,812.82	$1,898,868.00	...	$14,123.57	$3,328.60	$2,058,973.60	...	$786,159.39
Restricted Gifts and Grants—Exhibit D	62,378.08	...	...	53,166.35	...	43,281.76	...	72,262.67
Total	$991,190.90	$1,898,868.00	...	$67,289.92	$3,328.60	$2,102,255.36	...	$858,422.06

Note: Transfers to General Contingent Fund:

From Current Year's Appropriations—Schedule 4	$39,759.50
From Prior Years' Appropriations	2,426.79
Total	$42,186.29

SCHEDULE 4

STATEMENT OF EXPENDITURES AND BUDGET SUMMARY INCLUDING MISCELLANEOUS RECEIPTS FOR THE YEAR ENDED JUNE 30, 1955

	Salaries	Fellowships	Equipment (Exhibit F)	Other Expenses	Total Expenditures	Expenditures Against: Current Year's Appropriations and Other Credits	Expenditures Against: Prior Years' Appropriations
Departmental Research Operations:							
Department of Plant Biology	$71,718.38	....	$1,621.59	$15,477.66	$88,817.63	$85,028.27	$3,789.36
Department of Genetics	135,277.84	....	6,395.38	44,433.22	186,106.44	179,103.04	7,003.40
Dormitory and Mess Hall	1,934.08	....	....	5,673.84	7,607.92	5,635.33	1,972.59
Geophysical Laboratory	170,339.66	....	7,162.14	65,622.08	243,123.88	216,313.88	26,810.00
Department of Archaeology	69,380.58	....	128.96	22,198.22	91,707.76	87,841.46	3,866.30
Mount Wilson Observatory	218,768.03	....	5,223.30	48,851.12	272,842.45	257,379.05	15,463.40
Department of Terrestrial Magnetism	251,350.08	....	9,669.97	81,744.70	342,764.75	309,809.06	32,955.69
Department of Embryology	109,581.30	....	1,852.80	22,633.04	134,067.14	129,815.81	4,251.33
Total Departmental Research Operations	$1,028,349.95	....	$32,054.14	$306,633.88	$1,367,037.97	$1,270,925.90	$96,112.07
Administration	149,388.22	....	5,809.45	90,225.15	245,422.82	239,037.41	6,385.41
General Publications	....	....	....	37,841.33	37,841.33	13,982.71	23,858.62
Research Projects, Fellowships, etc.	8,033.21	$41,128.11	....	20,331.32	69,492.64	12,125.67	57,366.97
Pension Fund	....	....	....	127,309.69	127,309.69	92,062.55	35,247.14
Retirement Plan Contributions	....	....	....	211,869.15	211,869.15	89,437.45	122,431.70
Total	$1,185,771.38	$41,128.11	$37,863.59	$794,210.52	$2,058,973.60	$1,717,571.69	$341,401.91
Restricted Gifts and Grants (see contra income—Exhibit B)	24,114.82	....	....	19,166.94	43,281.76		
Total	$1,209,886.20	$41,128.11	$37,863.59	$813,377.46	$2,102,255.36		

Budget Summary

Budgets approved by Trustees:			
Appropriations July 1 to December 31, 1954	$915,309.00		
Appropriations January 1 to June 30, 1955	983,559.00		
Total Appropriations—Schedule 3		$1,898,868.00	
Other Credits—Exhibit B:			
Sales of publications	$5,671.75		
Proceeds from Dormitory and Mess Hall, Cold Spring Harbor	6,701.57		
Miscellaneous	1,750.25	14,123.57	
Transfer of unexpended current appropriations to General Contingent Fund—Exhibit B			39,759.50
Reserved from this year's appropriations for current liabilities and commitments—Exhibit B			154,792.64
Income added to Special Funds—Exhibit B	$1,735.47		
Less: Income July 1 to December 31, 1954 (not budgeted)	867.73	....	867.74
Total		$1,912,991.57	$1,912,991.57

REPORT OF THE PRESIDENT

OF THE

CARNEGIE INSTITUTION OF WASHINGTON

FOR THE YEAR ENDING JUNE 30, 1955

REPORT OF THE PRESIDENT

OF THE

CARNEGIE INSTITUTION OF WASHINGTON

In previous reports I have dealt with the current progress of research, a number of policies of the Institution, its relations to government, and such internal matters as a new kind of pension system. In this final report it is fitting to consider the more basic question why we pursue our course of fundamental research at all.

That our motivation is strong we have ample evidence, but we seldom attempt to analyze it. We follow our course so assiduously that we do not stop to consider where it leads or why we should pursue it. We tend to keep our eyes trained too constantly on the immediate steps before us and fail to look at the fine country that spreads away from us on either side. Though the areas of endeavor that surround us are often inspiringly beautiful, we ignore their long vistas or glimpse them but faintly. They are the goals of others, who with equal dedication and intensity pursue different courses from ours. Our road is that of fundamental science. One does not saunter along it with one's head in the air, for it is strewn with rocks and briars to catch the unwary.

Yet we follow it and climb its steep ascent with joy and eagerness. There are many side roads by which we could leave it, and these often lead temptingly down into fertile valleys where a less demanding life beckons, furnished with an abundance of all creature comforts. There would be no stigma upon us if we turned off on these spurs, and yet very few of us do. As a company, dedicated to a way of life, we are nearly unanimous in our acceptance of its customs and procedures. And our company certainly includes all members of the Board of Trustees, who find time in their busy lives for work in our behalf—work often in the nature of sheer labor, yielding no direct satisfaction but necessary for the furtherance of a total effort, whose chief satisfactions lie elsewhere and can be shared only imperfectly through our reports and meetings. The company also includes research assistants who wash a thousand petri dishes or solder a maze of wires, with only a vicarious participation in the grand elation of accomplishment.

What is it that joins us thus in common effort, and urges us on?

A cynic might give very simple explanations. Andrew Carnegie left a fund to be spent in this way; and we, perhaps, find the spending pleasant without giving much thought to our purpose. There have always been aspects of scholarly work that resemble a gentleman's game, made exclusive by a special jargon—Latin or some modern equivalent—and perpetuated by the presentation of a solid front of mutual acclamation in dealing with sources of support, however self-critical it may be within the closed circle of its participants. But no such cynical explanation will suffice to account for what we have here: a group of strong and able men, capable of deriving acclaim and reward from the world in other ways, who yet choose to pursue the path of science, though the individual steps of their advance are often appreciated only by their immediate associates and the pecuniary rewards for their effort are small. We must look deeper for our true motivation.

Our field is fundamental science. And by this I mean that we seek out the facts of nature and their interrelationships, without attempting to apply them immediately to the needs and desires of man for physical comfort, power to control the forces of nature, or freedom from disease. We seek to acquire and correlate knowledge, not to participate in its application.

Long ago we learned that, if we take our eyes off the main trail and view with too much interest the tempting side paths that lead to early practical application, we are likely to lose our way and to waste much time in struggling to find it again. Yet the fact that there are side paths for those who would follow them, and that our blazing of the main trail makes possible a digression into those byways where results helpful to material progress can be secured, is one true and worthy motive behind all we do. We know there may be a long interval between our work and its practical application, that the disconnected relations we find must often be joined with those found by many other investigators before a useful pattern emerges. And yet this does not trouble us; for we are conscious of the problems that the race will struggle with long after our work has been merged in the general advance of science, and later generations will finally complete work we have begun.

Thus we work on fundamental problems of genetics or embryology, the synthesis of proteins by bacteria, or the chemical nature of a virus. We are not concerned directly with the current improvement of domestic animals or plants, the practice of obstetrics, the biochemical production of antibiotics, or the control of virus diseases, even though some of our findings prove to be immediately applicable in all these fields, and we rejoice when this happens. The practice of medicine is still largely empirical; but some day it will rest on a more orderly base, and we would contribute to that achievement. The mechanisms of inheritance are just beginning to be understood in part; and we know, from the mysteries that confront us, that our theories will become far more elaborate and intricate before they become fully comprehensive. One of the greatest mysteries of life is how a minute chemical aggregation, controlling the division and diversification of cells, can produce the intricate, highly adapted organisms which we see all about us—how, in fact, it can produce an organism such as ourselves. We know that if we understood the process by which growth is controlled, much good might follow, including perhaps some control of the process when it becomes degenerative. Our whole lives are affected by the interplay between our organic structure and a host of simpler organisms, some of them beneficial, but most of them predatory and destructive. We are just now learning how these simple organisms operate, and learning that they are not so simple as we thought. The path toward a complete grasp of their biochemistry and structural organization appears to be a long one, which offers many fascinating opportunities for research along the course. And beyond the study of all other organic mechanisms lies the problem of man's mind itself, its chemical, electrical, and structural aspects. The study of this problem, as well as of theoretical and experimental psychology, is basic to any scientific investigation of the subtler regions beyond, which may include phenomena that are explicable in no familiar terms. This subtler region must be understood more fully or at least defined if we are ever truly to know ourselves, our possibilities, and our limitations.

As we regard the present material progress of man and his probable future, we can see that he is headed for catastrophe unless he mends his ways and takes thought for the morrow. This is quite apart from the immediate question whether he will use the split atom or a trained virus to turn civilization back and force it to begin again its slow upward climb—apart from the question whether great wars can be avoided through a general understanding of their consequences. These are momentous questions, but they are immediate ones, and so they must be resolved by other patterns of thought than those of long-range fundamental science, which, though it may profoundly influence the fate of future generations, can affect

the present course of events only rarely. They are questions in which all scientists are deeply interested, but primarily as citizens and members of the community—questions to which they can contribute only as citizens or as their background in science enables them to counsel wisely with those who apply science and those who apply other disciplines, all of whom today find some pertinence of science to their problems.

But, wars aside, man is still headed for trouble. The world's population is increasing at a rate which renders distress, famine, and disintegration inevitable unless we learn to hold our numbers within reason. New methods of extending the food supply, powerful though they may be, can only postpone the crisis, and perhaps allow time for communication and education to produce the general understanding that is essential to a sound solution of the underlying problem. There is no doubt that we can go far in providing new means of sustenance for great masses of people. The cultivation of that enormous reservoir, the sea, can yield richly if we learn to control organisms and species; and our land is far from exhausted if we learn to use it well. The transformation from a hunting and gathering culture to a culture dependent on herding and agriculture permitted a manifold increase of population and a simultaneous increase in physical welfare, and this could happen all over again and postpone temporarily the catastrophe predicted by Malthus. The process production of foods is just beginning. An understanding of photosynthesis and the creation of its synthetic equivalent could unlock stores of vital materials beyond our present power to envisage. Our control and training of natural species and the creation of new species at will for explicit purposes, especially species of lower organisms, hold enormous possibilities. And all this depends on our progress in understanding life itself, which is the subject of fundamental biology.

Man is using up his resources at an appalling rate, and his demand on them is growing exponentially. What is he going to use for his various purposes in the future? The problem of energy sources is not nearly so baffling as it appeared a while ago. True, we are exhausting our fossil fuels, in spite of our great coal reserves and our continued discovery of new sources of oil; for we consider the long pull, and not just how to keep our mounting horde of automobiles running for another decade or two. But atomic energy has been produced and practically applied, and although it is not yet economically competitive with fuels except under unusual circumstances, it soon will be. Atomic fuel, moreover, will become almost inexhaustible for practical purposes if we learn, as we sometime shall, to utilize the process of fusion as well as that of fission. We have also the prospect of solar energy. This is truly inexhaustible as long as the sun shines; and the astronomers tell us it will shine for a long time to come. We have numerous ways of applying solar energy for our purposes. One way, through special means of utilizing thermal cycles, is perhaps economically feasible right now in some applications if anyone is sufficiently interested to undertake the task of developing it on a broad scale. But, for the long pull, photochemical and electronic methods of exploiting the sun's energy will undoubtedly take precedence. We already have photoelectric surfaces efficient enough for the purpose, but they need to be made cheaper. As yet we do not know enough photochemistry to do the chemical job well, but we probably soon shall, and then great ponds of chemicals will gather our energy for us, and our chemical engineers will convert it into convenient forms for our diverse uses. On the whole, then, we can probably keep up with our demands for energy for a long time to come.

But it is a different matter with our mineral resources. We can see the end of

the process of just digging metals out of the ground wherever we find a surface indication that they may be present. We can use aluminum and magnesium, to be sure; for there is plenty of the former in clays and of the latter in the sea; and we shall in all probability have the energy available with which to recover them. But in the kind of civilization we are building, we need more than these for our alloys and our chemical processes. We have learned to transmute elements, and we do so at present to our disadvantage whenever an atomic energy plant is operated, but this would seem to be an exceedingly inconvenient and meager source of the elements which will in the future be in short supply. For a long time to come we shall be dependent on finding and exploiting natural deposits. This will involve placing geology on a firmer scientific basis. It has progressed notably in this direction during the past generation. But we need to know more of the chemistry of rocks, the movement of materials in the crust, mountain building, the metamorphoses that have occurred, and the thermal and atmospheric conditions of the past. We need to know whether the poles have shifted, and if so where they have moved, whether the skin of the earth has slipped over its core, and whether it is still slipping. We need to know how the sun has influenced the course of events on this planet, not only by warming it, but in numerous other ways. We need to understand atmospheric circulation and with it weather and climate, both of the present and of the remote past. When we learn all these things we can search for ores more intelligently, and we shall, no doubt, find great resources. We shall also learn to recover and process them better, perhaps without the need of having men work underground. Eventually, perhaps, we shall learn to train organisms to recover metals for us from the sea, as indeed seems to have been done at times in the past.

Is all this the sole motivation of fundamental science: to prepare the way for later useful applications and thus fend off a racial catastrophe? And do we always have it clearly in view? Of course not. A great deal of research is done as a matter of habit, because it is the fashion of the time or the practice of the community. We seldom stop to think of why we do what we do; in fact, we seldom think philosophically at all. Many a research program is conducted in which the researcher has no clear idea as to just what he is trying to find out or what it would mean if he found it. Men work for years without stopping to examine critically the relevance of their efforts. Curiosity is often the underlying motivation, and not a bad one. It was probably responsible for the discovery by Prometheus of how to make a fire. Emulation is often clearly present, especially when a great scientist is surrounded by disciples. The competitive spirit, fortunately now on a more friendly basis than in the past, has a strong part in scientific motivation. It has become less artificial and less acrimonious as caste distinctions and false pride have lost their hold and as the stuffed shirts among us have dwindled almost to extinction. And the sporting instinct, whatever that is, which causes men to pit themselves against great odds, to revel in trial and adversity, to breathe the stimulating air of self justification in success, no doubt is often present. We do what we do for many unavowed reasons, and seldom pause to analyze them. But when we do reflect, we find that our primary motivations in scientific effort extend far beyond our casual and momentary reasons, even beyond the thought that what we do may, in its small way, benefit the human race in its struggle to control its environment and itself in the grim days that are sure to come.

For the scientist lives by faith quite as much as the man of deep religious convictions. He operates on faith because he can operate in no other way. His depend-

ence on the principle of causality is an act of faith in a principle unproved and unprovable. Yet he builds on it all his reasoning in regard to nature. This is even truer today than it was some sixty years ago when William James so forcibly reminded us of it. Some of us, confronted with the bizarre as we delve into the nucleus of the atom or try to pin down the elusive electron, wobble sometimes in our basic faith that natural events are determined by unique causes, that, from a physical standpoint, the present fully determines the future. We become confused as to whether, when we include ourselves as a part of the system, causality is departed from. But we still proceed in our daily round on the assumption of unique cause and effect as the basis for all our experimentation. It is becoming apparent also that the acceptance of any system of logic for reasoning about our sensory experience is an act of faith, and that our reasoning appears sound to us only because we believe it is and because we have freed it from inconsistencies in its main structure; for it is built on premises which we accept without proof or the possibility of proof.

Rigid determinism leaves no place for chance. It holds that the configuration of the present moment uniquely and completely determines all the future, and that it has always been so. My thoughts and yours, as well as our actions, at some time tomorrow, according to this view are completely specified by nothing more than the present instant positions and velocities of a myriad of particles of matter and of energy. Strict determinism can brook no interference whatever with this rigid system, no options, no alternatives, no chance. Yet the physicists themselves have recently introduced chance into the systems they construct, driven to it by their observations and their attempts at unifying theories. An electron no longer occupies a fully definable position with an equally definable momentum. All we can measure, all we can know exists, is a probability of its state. Though we started with a confident reliance on causality, it now appears that even in the accounts of the world which science constructs from experiment there must be admitted an unpredictability, and a future which is indeterminate.

Yet scientists have built a magnificent structure of materialism, ranging from a cosmos which has developed from a primeval explosion some billions of years ago to the mechanisms by which a child learns to cerebrate. Without a qualm, they view the origin of life on the planet as the result merely of the appearance of self-duplicating molecules in an ancient soupy sea. They seek to explain most of our acts and thoughts as reactions between a genetic constitution and its environment, and to explain most of our code of ethics as the result of lessons learned in the struggle for survival as individuals and as members of the family and clan.

With the background which science thus furnishes, we view the universe from a height—not yet from a mountain perhaps, but with a broader range of vision than was available to our fathers. Our reactions to the scene before us are widely varied. On the one hand we contemplate the terrifying spectacle of an unfolding material universe. Some six or seven billions of years ago a single giant molecule disrupted and threw its substance into space. There condensations of the dust formed galaxies, and then stars in uncounted number, rushing apart at stupendous velocities. On one planet of one star organic life began and developed into man, endowed with a passion for survival, fighting all that stood in his way. In other organic manifestations, the same sort of process was probably under way simultaneously on many other satellites among the distant galaxies, blessed with the rare conditions of favorable temperature and atmosphere. The whole universe is running down, its entropy increasing fatefully, its atomic energy destined to keep the stars

lit for a time before they fade into the cold of interstellar space. Extinction, individually and for the race, is the only outcome. It is an inexorable mechanical process in which all the intricacy of life is but the glitter caused by an interaction of primary particles and energy—a fateful dance of molecules and their parts, in which we are but a minor incident.

But there is another way of reacting to the scene. Man is weak, but he has learned to supplement his senses by powerful instruments of perception and measurement, his muscles by subjecting primal energy to his control. Far from being imprisoned in his world, he gazes out over vast intervals of space and time. Turning inward, he unravels the mysteries of the minute components of all matter and charts relations which enable him to foretell the future with workable if not absolute assurance. He is beginning, moreover, to fathom the nature of space and time themselves, in ways that were inconceivable before, as his simple patterns of thinking have become elaborated into magnificent patterns of symbolic reasoning. He has risen, in his best moments, above the mere struggle with his environment, and has achieved a measure of human dignity—humble before the vast mystery that surrounds him, ever extending his vision and comprehension; no longer terrified by the unknown; not yet, perhaps, firm in his hope, but confident that what he has done so far is only a beginning and that to be a man with a man's consciousness is important in the drama that he witnesses.

If one follows strictly a philosophy of materialism, one comes at last, inevitably, to the problem of free will; and men have wrestled with that question ever since they began to reason. Your strict materialist will argue that free will is only an illusion, that the dance of the molecules from the beginning determined uniquely that some of us should believe in this illusion. But there can be no profit in arguing about the matter; it cannot be proved one way or the other by any system of logic or by any amount of observation or experiment. If a scientist believes in free will, he does so as an act of faith, an act of faith superposed on the other acts of faith which underlie his whole system of research and thinking. Yet few scientists act as though they considered themselves mere marionettes in a puppet show, dancing vainly in a meaningless universe. They act as though they could by conscious choice influence the course of events about them, and as though they intended to do so. Even in Russia, where materialism is the official philosophy and the state substitute for religion, the controlling group do not act as though they felt they were mere observers of an inevitable and unalterable mechanistic evolution. Scientists do not talk much about the subject these days; it is no longer fashionable to argue interminably about metaphysics, and scientists are generally too busy to indulge in the sort of reasoning that commonly goes under the name of philosophy. They seem to find it unsatisfying to their disciplined minds. But, having watched scientists for many years, I have no doubt that nearly all of them believe in free will. And when one has admitted this faith into the rigid systems postulated by materialism, one has abandoned materialism altogether. The way is then open for other faiths to follow.

Scientists build a theoretical universe, based on a system of experiment, observation, and logic; and in so doing they assume causality as an act of faith. Their logic has no other basis, in fact, than their confidence in its validity, with no other support for that confidence than their willful acceptance of it on a pragmatic basis. The system seems to work and to produce a satisfying account of what occurs about us, one that is useful for our purposes, and an account of our past which, up to a point, fits together well. And in building this structure, by their arbitrary and pragmatic processes, they exemplify at all times that they also believe they have a choice as to what they do. This means that they believe that, in

addition to the external universe of which they construct their account, there is present in themselves, over and beyond their restricted view, some other reality, not to be accounted for by their methods. For no one looks on the current scene with more freedom of spirit than the scientists, whose vision is both broad and deep, but who must at all times understand the limitations of their own methods if they would avoid fallacy and the false application of those methods where they inherently do not apply.

So, back of all other motivations, there is a deeper one, vague in outline, seldom expressed, often denied, yet powerful in its influence. Its ultimate expression is beyond our ability. For the present it can be expressed in the faith that man can learn to know and to understand and that it is good to exercise that power and to strive for the extension of our wisdom. This is the primary faith that carries men of science forward in their great adventure. No other faith is necessary for the scientist in his work, though many scientists are also deeply religious. It is enough for him to take part in the struggle, to influence it in its course in little ways by his acts of free will, to participate in the drama even if its meaning is beyond the scope of his finite mind. It is this faith and this sense of participation, acknowledged by scientists only in their rare thoughtful moments, that leads them forward, just as it is faith of some kind that has caused men of all callings in all times to strive and to hope.

There are thus many motivations that impel the scientists of the Carnegie Institution of Washington to follow the path of fundamental research. They are greatly privileged; for they are free from the distractions of momentary goals, and they may choose their own special lines of investigation whatever their avowed motives, whether scientific curiosity, or the desire to serve their fellow men. They are, in fact, motivated, though they will seldom declare it, by something far deeper—something that each man defines for himself in the quiet of his laboratory or study, something that he does not often expose to the analysis and criticism of his colleagues, but that nevertheless he lives by.

This is my last report. I shall hereafter watch you from a distance with interest. No doubt I shall watch at times with a critical eye, as some young scientist I have known, and shall continue to know, pursues his strange and erratic way toward eminence in his profession. At times, I trust, I shall watch with amusement the gyrations of some members of the staff as they exhibit the individualism that is a prerogative of genius. I shall always wish you luck, for luck is an essential ingredient of successful scientific careers. I shall expect from you results, some as the sparks of genius, some as the results of long-continued patience and application. For all of you I hope there will be exultation in success, even as you school yourselves not to be discouraged by temporary failure. Though completely divorced from the ordering of events, which are properly the concern of younger men, I shall continue to be a member of the staff just as all who retire continue to be in spirit. Above all, I shall watch your work with confidence, for I know that you will adhere to the faith that, however seldom expressed, has carried us on together for many years. It is a faith that makes us look beyond tomorrow and ever seek to know, because in some mysterious way we realize that only a small portion of the road to knowledge has yet been trod, that matters beyond our present comprehension lie just around the bend, and that it would be folly at any point to abandon the journey in skepticism without striving to surmount the next obstacle and perhaps attain a better view.

You are members of a distinguished and worthy company. Treasure the privilege of your association in your hearts.

Vannevar Bush

REPORTS OF DEPARTMENTAL ACTIVITIES AND CO-OPERATIVE STUDIES

ASTRONOMY

Mount Wilson and Palomar Observatories

JOINT COMMITTEE ON
IMAGE TUBES FOR TELESCOPES

TERRESTRIAL SCIENCES

Department of Terrestrial Magnetism
Geophysical Laboratory

BIOLOGICAL SCIENCES

Department of Plant Biology
Department of Embryology
Department of Genetics

ARCHAEOLOGY

Department of Archaeology

MOUNT WILSON AND PALOMAR OBSERVATORIES

Operated by the Carnegie Institution of Washington
and the California Institute of Technology

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During the present report year several major projects have been completed and published or made ready for publication. The purpose of the first of these projects was the accumulation of data for a critical evaluation of the velocity-distance relation of galaxies.

In 1929 Hubble made the first announcement of a linear relation between the distances and the velocities of recession of a number of galaxies that had then been observed. This observational relation led directly to the concept of the expanding universe. Because of the very fundamental importance of this concept to cosmology, the Observatories have had in progress for many years a program to extend improved velocity and distance measurements to a large number of galaxies, and in particular to increase the range of these measurements out to the most distant observable galaxies.

The observations of velocities have been carried out chiefly by Humason, first with the 100-inch and more recently with the Hale telescope. The velocities of a total of 620 galaxies have now been measured. These include velocities up to approximately one-fifth that of light, or 60,000 km/sec. The determination of the distances of these galaxies depends on their magnitudes. Consequently a parallel program was started by Pettit in 1947, which was planned to provide a photoelectric determination of the magnitude of each of the galaxies for which velocities were available from Humason's program. The measurements of the velocities and magnitudes were completed at the end of the year. These results are being interpreted by Humason, Sandage, and Dr. Nicholas Mayall, of the Lick Observatory.

Hubble in the course of his lifelong study of galaxies had developed a system of classification for the various types of these objects. At the time of his sudden death in September 1953 he had nearly completed an extensive revision of this classification and had in preparation definitive descriptions of these types, illustrated with photographs. Sandage has taken charge of the completion of the illustrated volume which will contain this classification. In order that the critical features of the various types might be shown in the finest possible detail, Hubble and later Sandage have obtained 200-inch photographs of many of the standard types to replace the earlier 100-inch plates.

The third major project was the establishment of a precise photoelectrically determined magnitude scale extending down to the faintest observable stars in several areas distributed in such a way that at least one of the areas is always visible in the night sky for comparison. These accurate magnitude standards are of great importance to many of the programs being carried out at the Observatories. For example, the distance measurements to all objects not in the immediate neighborhood of the sun depend on the comparison of the apparent magnitude of an identifiable object with its absolute magnitude. Likewise,

many of the current theories of stellar evolution are constructed on the basis of the color-magnitude relations found in various stellar clusters.

The project was initiated in 1947 by Drs. Joel Stebbins and A. E. Whitford, of the Washburn Observatory, using the 100-inch telescope as a light-collector for their own photoelectric equipment. They measured the magnitudes of about 100 stars in three selected areas, extending down to about the 18th magnitude. Since 1950 this program has been extended by Baum, using first the 100-inch on Mount Wilson and more recently the 200-inch Hale telescope. With the aid of the latter instrument and of the photon counter which Baum developed for this project, he was able to extend these measurements to about the 23d magnitude in three selected areas and to the 19th magnitude in six other areas. Since the faintest stars that can be photographed with the Hale telescope are of about the 23d magnitude, the project has therefore provided standards for use throughout the range of this instrument. The magnitudes of about 400 stars have been standardized. In agreement with the original findings of Stebbins and Whitford, Baum's results indicate that the errors of the older magnitude scales based on photographic procedures increased with magnitude, reaching 0.5 magnitude around the 19th magnitude and becoming even greater near the limit of the telescope.

OBSERVING CONDITIONS

Mount Wilson experienced another dry year, with a precipitation of 25.57 inches or about 70 per cent of normal. Solar observations were made on 341 days between July 1, 1954 and June 30, 1955. During this same period observations were made with the 60-inch telescope on 275 nights and with the 100-inch on 316 nights.

SOLAR RESEARCH

Solar Photography

Solar observations were made by Cragg, Hickox, Nicholson, Richardson, and Dale Vrabec during the year. The numbers of photographs of various kinds taken between July 1, 1954 and June 30, 1955 were as follows:

Direct photographs	674
Hα spectroheliograms, 60-foot focus	321
Hα spectroheliograms, 18-foot focus	1,008
K2 spectroheliograms, 18-foot focus	1,026
K2 spectroheliograms, 7-foot focus	58,500
K prominences, 18-foot focus	1,158

Sunspot Activity

The magnetic classification and study of sunspots and related phenomena have been continued by Nicholson and Cragg. Cooperative programs have been carried out with the U. S. Naval Observatory, the University of Michigan, the Observatory of Kodaikanal, the Meudon Observatory, and the Central Radio Propagation Laboratory of the National Bureau of Standards. During the calendar year 1954, solar observations were made at Mount Wilson on 337 days, 213 of which were without spots. The total number of spot groups observed in 1954 was 46, compared with 93 in 1953 and 219 in 1952. The northern hemisphere was the more active, having 27 groups while the southern had 19.

Sunspot minimum occurred in April 1954, making the length of the last cycle 10.1 years, the fourth consecutive cycle shorter than 10.5 years. The 1954 minimum was the lowest since 1913. The sunspot curve before minimum was very similar to that before the minimum of 1944.

At the end of 1954, spots of the new cycle were outnumbering those of the old cycle 7 to 1, but in the first half of 1955, 53 new cycle groups and only 1 old cycle group have been observed.

The monthly means of the number of groups observed daily for the past two and one-half years are shown in table 1.

Three flares of intensity 1, and none of intensity 2 or 3 were recorded in 1900.3 hours of observing. The average number of flares per 100 hours of observing was 0.2 in 1954, 0.2 in 1953, and 1.6 in 1952.

TABLE 1

Month	Daily number of sunspot groups		
	1953	1954	1955
January	2.4	0.0	2.2
February	0.5	0.1	2.2
March	1.2	0.5	0.6
April	2.3	0.3	1.4
May	1.2	0.1	2.3
June	1.9	0.0	2.4
July	0.6	0.6	..
August	2.0	0.8	..
September	2.8	0.3	..
October	0.8	1.4	..
November	0.2	0.9	..
December	0.3	0.7	..
Yearly mean	1.4	0.5	..

Magnetic Polarities

Magnetic polarities in each spot group have, if possible, been observed at least once. The classification of groups observed between July 1, 1954 and June 30, 1955 is indicated in table 2. "Regular" groups of the new cycle in the northern hemisphere are those in which the preceding members have N (north-seeking) polarity and the following members S polarity; in the southern hemisphere the polarities are reversed. "Regular" groups of the old cycle are magnetically opposite to those of the new cycle.

TABLE 2

Hemisphere	Regular		Irregular		Unclassified	
	Old cycle	New cycle	Old cycle	New cycle	Old cycle	New cycle
North	3	37	1	2	1	11
South	3	24	0	1	0	6
Whole sun	6	61	1	3	1	17

Solar Magnetic Fields

Daily recording of the weak magnetic fields of the sun has been continued with the magnetograph at the Hale Solar Laboratory in Pasadena by H. D. Babcock and H. W. Babcock with assistance from Cragg. Complete records were obtained on only 158 days of the year, largely because of unusually poor atmospheric conditions during the first half of 1955.

Many bipolar magnetic (BM) regions associated with the new cycle of solar activity have been recorded, but no prominent unipolar (UM) regions have been observed. These, however, are expected to be weak and scarce except in the declining years of the sunspot cycle. Continued evidence has been found for the weak, high-latitude general magnetic field, of the same polarity as reported last year. There is some evidence for variations in total effective magnetic flux, but discussion of this will be more definitive after a long and better-calibrated sequence of observations has been obtained.

The sequences of solar magnetograms obtained in 1952–1954 have been further analyzed and compared with other records. This has led to the proposal that solar corpuscular emission (a concept now widely accepted) is much enhanced over regions of the sun's surface where there are coherent magnetic fields of intensity one-half gauss or more. Such regions are the BM and UM regions of low heliographic latitude, and the polar regions in which evidence of the general field is found. Turbulence in or near the photosphere is seen as a necessary condition for the enhanced corpuscular acceleration in the presence of a magnetic field. A tentative mechanism has been proposed in which turbulence generates upward-accelerated constrictions in the magnetic tubes of force; tenuous clouds of gas (neutral but ionized), unable to escape from the tubes because of their high conductivity, are squeezed ahead of the constrictions and accelerated to velocities of some hundreds of kilometers per second.

Above the photosphere the corpuscular streams are guided by the magnetic lines of force.

The concept set forth above provides an attractive explanation for a number of solar phenomena. Over UM regions, the corpuscular streams moving continuously outward cause 27-day recurrent geomagnetic phenomena if the streams happen to interfere with the earth. (Low-energy cosmic rays from the same sources account nicely for the 27-day peaks in neutron intensity, of advanced phase, that have been reported by Dr. J. A. Simpson, of the University of Chicago.) Above solar BM regions, particles are accelerated upward along both sides of the arching lines of force; they collide near the tops of the arches, generating radio noise, and condense to form the precariously supported clouds that are observed as prominences. During their upward acceleration through the corona, it is supposed that the corpuscular streams and the associated hydromagnetic waves excite the monochromatic radiations of the corona that are observed both in low latitudes and in the vicinity of the poles.

Solar Spectrum

A detailed study of the line contours of various lines in the solar spectrum has been undertaken by Rogerson. A photoelectric photometer has been designed and built to scan the solar spectrum produced by the 150-foot solar tower. The output of the photometer is a tracing of intensity versus wave length drawn automatically on a strip-chart recorder. The effects of atmospheric seeing and transparency fluctuations are almost completely eliminated by monitoring the intensity of the solar continuum and recording the ratio of scan-to-monitor signals. The usable wavelength range is roughly from 3700A to 6700A with the present phototubes.

The photometer was first used to trace three forbidden lines of *O* I at λλ5577.350, 6300.32, and 6363.75. From these an abundance determination was made that yielded an abundance of 13.5 mg of oxygen per cm^2. This compares with a value of 18 mg given by Bowen in 1948 and a value of 10 mg estimated earlier by D. H. Menzel and collaborators.

The profiles of a number of atomic lines are being analyzed to detect the presence of turbulent motion in the solar atmosphere, and possibly its variation with depth.

The discovery of the unstable element *Tc* I in the S stars by P. W. Merrill led to a tentative suggestion by others that *Tc* II existed in the ultraviolet solar spectrum. Greenstein has reinvestigated this question in collaboration with C. de Jager. Plates taken by H. D. Babcock were analyzed, and the intensities of the lines ascribed to *Tc* II interpreted theoretically. If these lines were *Tc* II, the abundance of technetium would considerably exceed that of any other stable nucleus near it in the periodic table. From the λ3195 line the deduced Tc/H ratio is 10^{-9}. This abundance is so improbably high that it seems best to conclude that λ3195 is not *Tc* II, and that there is no evidence for the presence of technetium in the sun.

PLANETS AND SATELLITES

Some 1300 photographs of Venus in ultraviolet light were obtained by Pettit and Richardson between December 29, 1954 and March 29, 1955, when the fraction of the disk illuminated ranged from 0.32 to 0.75. Markings of a roughly banded type were always present, similar to those observed earlier by Ross and others.

The best images obtained January 29, when the disk was half illuminated, show three well-defined belts in the southern hemisphere. The orientation of the axis of the planet was calculated from measures on these bands, assuming them to be parallel to the equator. The position of the north pole came out $\lambda = 8°$, $\beta = +73°$. This

gives 14° as the inclination of the equator of Venus to the plane of its orbit. From similar observations Kuiper has recently found for the position of the north pole $\lambda=79°$, $\beta=+59°$, with an inclination of 31°. The mean of the two investigations gives an inclination of 22°, indicating that Venus has an axial tilt about the same as that of the earth and Mars.

Tracings made parallel to the terminator at distances of 0.14 and 0.34 radius give dish-shaped intensity curves, about 20 per cent weaker at the center than at the cusps. As usual, the southern cusp was the brighter. At 0.59 radius the intensity curve is nearly flat. At 0.8 radius the shape of the curve is entirely altered, showing a rapid rise and fall relative to the bright central point nearest the limb.

Tracings perpendicular to the terminator show a linear rise in brightness to about 0.2 radius from the center, after which the brightness increases more rapidly than the linear rate to the maximum at 0.75. For Venus in visual light and for the moon at the same phase the rise in intensity is practically a straight line. The results for Venus in ultraviolet light (eff. $\lambda=3600$) agree with those found by Ross in 1927 when Venus was 0.38 illuminated.

A series of photographs of Mars was taken by Pettit and Richardson during the very close opposition of this planet in the summer of 1954. One of the most interesting features observed was the W-shaped marking over the equator from 66° to 120°. The marking appeared only in blue light and presumably was a high cloud in the Martian atmosphere. The observations, which were confined to June 2 and 3 and July 3, showed the marking to be at essentially the same position on each of these dates, from which it was assumed that the marking was fixed in the atmosphere, moving at the same rate as that at which the planet rotates. When the W was plotted on the map of Mars for 1954 published by the Association of Lunar and Planetary Observers, its "knobs" were found to fall near the oases Arisia Silva, Ascraeus Lacus, Tithonius Lacus, and Hebes Lacus; two strokes connecting the knobs fell near the canals of Ulysses and Fortuna.

Intensity curves across the disk of Uranus were made from some good 1.55-mm images obtained January 29, 1955 at the coudé focus of the 100-inch with an exposure of 0.9 second in integrated light. The south pole of Uranus was oriented at an angle of 39° with the line of sight. These curves were compared with similar curves made from images of Jupiter, 13 mm in diameter, obtained at the 100-inch on April 22, 1954. The intensity curve for the disk of Uranus was plotted on the same scale as that for Jupiter. No significant difference could be seen between the intensity curve for Uranus in integrated light and that for Jupiter in blue and yellow light.

Tracings across Jupiter perpendicular to the equator show much greater contrast in the belts in blue light than in yellow, a fact which is apparent from direct inspection of the images. Relative to the dark equatorial belt, the northern adjacent light belt had an intensity of 0.7 in yellow light and 0.45 in blue light.

Positions of Jupiter's faint satellites were obtained by Nicholson from photographs with the 60-inch and 100-inch telescopes.

The diurnal variation of geomagnetic activity has been studied by Nicholson and Dr. Oliver Wulf, of the U. S. Weather Bureau, using the eight 3-hour-range indices (K) for the nine years 1940–1948 and for six low-latitude stations fairly uniformly distributed in longitude. In addition to the expected local-time component, a universal-time component was found which varies with the seasons. It is suggested that features of the large-scale circulation of the atmosphere may contribute to the universal-time component.

STELLAR SPECTROSCOPY AND PHOTOMETRY

Approximately one-half of the observing time of the 200-inch, 100-inch, and 60-inch telescopes has been devoted to spectroscopic studies. During the year 617 spectrograms have been taken with the 200-inch, 865 with the 100-inch, and 222 with the 60-inch telescope.

Variable Stars

Observations of SS Cygni have been continued by A. H. Joy. The spectral behavior is similar to that of AE Aquarii. The absorption lines of the late-type component are heavily veiled by the continuum of the hot star even at minimum of the nova-like light-variation. The period seems to be less than one-half that of AE Aquarii.

Spectrograms of 12 faint RR Lyrae variables were obtained by Joy in order to supply approximate radial velocities for the stars observed for cross motion by van Maanen some years ago.

Sanford has completed his study of the radial-velocity variations of T Monocerotis and SV Vulpeculae, two cepheid variables of 27 and 45 days' period, respectively.

The program of simultaneous photoelectric and spectroscopic observations of faint, rapid variable stars, begun in 1953, was continued during 1954 by Wilson and Walker. Additional observations were obtained of Eggen's variable BD $+41°119$, and of HD 199908. The latter star is of spectral type F, and has a period of about 2 hours and a light-range of around 0.05 mag. The photometric observations of these two stars were obtained using the 20-inch reflector on Palomar, while the spectroscopic observations were obtained with the coudé spectrograph of the 200-inch reflector. Both photoelectric and spectroscopic observations of Eggen's extremely rapid variable, HD 223065, were made at the coudé focus of the 200-inch, since the declination ($-43°$) of this star placed it beyond the reach of the 20-inch.

In the course of the program of observations to detect short-period light-variations in old novae, discussed in the preceding annual report (Year Book No. 53), Walker found that Nova DQ Herculis (1934) is an eclipsing binary having the shortest known period, $4^{h}\,39^{m}$. He obtained 1530 photoelectric observations of DQ Herculis on six nights during 1954 with a photoelectric photometer attached to the 100-inch telescope. The star was observed in yellow, blue, and ultraviolet light.

The light-curve is very similar to that of the other known binary of comparable period, UX Ursae Majoris. Both light-curves are of the Algol type, and in neither star is there a detectable secondary eclipse. Other similarities include a minimum in the light-curve at 0.7P, occasional shoulders before and after eclipse, asymmetry of the rising branch of the eclipse-curve, and irregular intrinsic light-variations.

A unique feature of the light-curve of DQ Herculis is the occurrence between phases 0.11P (the end of the eclipse) and 0.32P of rapid variations in light having a period of 1.180 minutes and a range of 0.07 mag. in the ultraviolet. These periodic variations were observed on the three different nights when continuous deflections were taken on the star during the above-mentioned phase interval; thus, they appear to be relatively permanent features of the light-curve. Photometric elements of the system have been derived using J. E. Merrill's nomograms. Assuming that the secondary star is of zero surface brightness, that the coefficient of limb darkening is 0.6, and that the orbit is circular, the elements of the system are: nova component, $r_s = 0.30$, secondary, $r_g = 0.37$; the inclination of the orbit is $i = 76^{\circ}.7$; assuming a mass ratio of unity, the densities of the stars are $\rho_s = 6.6\rho_\odot$ and $\rho_g = 3.7\rho_\odot$.

Using the distance of the star given by the expansion parallax of the shell, and the effective temperature (10,000° K) deduced from the B−V color, the "absolute" radii of the stars are $R_s = 0.10R_\odot$ and $R_g = 0.11R_\odot$. The absolute visual magnitude

of the nova is $M_v=7.4$, and from the absence of a secondary eclipse the brightness of the companion is $M_v \geqq +10.7$.

Zwicky has found that the number of variable stars of all kinds in high galactic latitudes increases rapidly for stars fainter than $m_{pg}=17$.

A new search program for supernovae has been organized by Zwicky, covering seventy fields to be taken with the 18-inch schmidt telescope. It is intended to search one thousand near-by galaxies during the next five years for apparently bright supernovae. During the preliminaries of this program Wild discovered three supernovae in 1954.

Pettit has continued to make photometric measures of Nova Puppis. Its present visual magnitude is 13.85.

A program of photoelectric observation on the U, B, V system has been instituted by William G. Tifft to study the general characteristics of the cluster-type variables in the galactic field. Spectrographic observations are also being made with the new 60-inch Cassegrain spectrograph. The primary objective is to obtain a statistical comparison of the galactic variables with those in globular clusters; detailed studies of individual stars will be made only if warranted. A photoelectric light-curve of the type c cluster variable T Sextantis has been obtained in three colors. The star repeats very well from cycle to cycle, with changes of about 0.03 mag. in the yellow and blue. The light-curve in the ultraviolet seems to be much more erratic.

Globular and Galactic Clusters

In recent years it has been shown that a large fraction of the stars in the universe belong to population type II, whose properties differ substantially from those of the stars of population I, found in the neighborhood of the sun. The globular clusters provide the closest large samples of a pure type II population of stars. It has therefore been of great importance to study the stars in these clusters.

The color-magnitude diagram of the globular cluster M 15 is being investigated by Baum and Osterbrock. A number of blue and yellow direct plates of this object have been obtained by Osterbrock, using the 200-inch telescope. To calibrate these plates Baum has measured a sequence of 30 standard stars in the cluster, ranging from about 14th to 23d magnitude, with the Palomar photon counter.

Arp and Dr. H. L. Johnson, of Lowell Observatory, have completed a photometric study in three colors of the globular cluster M 13. The color-magnitude diagram has been carried to $V = 17.6$. This level is about 3 magnitudes below the horizontal branch. The sequences are similar to but not identical with those in the other clusters studied so far in the Observatories' program on these objects. There are a few RR Lyrae variables in this cluster. The population of the entire horizontal branch redward of the variable-star domain is also low. M 13 is unique, however, because of the large population density of very blue stars in the region bluer than the variable-star domain on the horizontal branch.

The three-color observations in M 13 show that there is an ultraviolet excess of about 0.05 mag. for the giant and subgiant stars. This is considerably smaller than the excesses found in NGC 4147, M 3, and M 92, which were reported last year. The reason for this difference is not known. The position and shape of the subgiant sequence in M 13 differs significantly from that in M 3.

Dr. and Mrs. R. H. Baker have completed extensive measurements and reductions of 41 plates of the globular cluster M 3 taken in ultraviolet light. These plates were taken by Sandage with the 100-inch telescope in order to study the light-curves of selected variables of the RR Lyrae type in the wavelength region from $\lambda 3300$ to 3800A. The ultraviolet curves obtained by the Bakers will be used in conjunction with the light-curves in m_{pg} and m_{pv} obtained last year by M. S. Roberts and

Sandage. Partial analysis of the material is complete and shows that the three-color material contains important information concerning the effect of changes in the electron pressure on the continuous energy distribution of these stars throughout the pulsation cycle.

An investigation of the RR Lyrae stars in the globular cluster NGC 4147 was started by Ray L. Newburn, Jr., from a series of 100-inch plates taken in two colors by Sandage. These plates were blinked and 17 definite cluster-type variables were found; 2 suspected variables of small amplitude were also noted. Previously, only 4 RR Lyrae stars were known in the cluster. Light-curves in two colors for these 19 stars will be obtained by Newburn, using standards from a previous photometric study by Sandage and Walker of the nonvariable stars in NGC 4147.

William G. Melbourne has completed a color-magnitude diagram of the giant globular cluster M 22 from plates taken by Arp with the 60-inch. Magnitude standards, used for calibration, were determined by Arp photoelectrically with both the 60-inch and 100-inch telescopes. The diagram was carried to $M_v = +2$. This cluster is of great importance since it is located at galactic coordinates $l = 337°$ and $b = -9°$, projected upon a rich star field which is part of the high-density region concentric with the nuclear bulge. A color-magnitude diagram of the background field slightly north of M 22 was begun. Differential comparison of the diagrams for the cluster and the background field promises to provide a direct test of the nature of the nuclear stars. In particular, this test will determine whether these nuclear stars are similar to those in globular clusters.

The reduction of the photoelectric observations of selected red giant stars in M 3 and M 92 has been completed by Walker. In each cluster, only stars falling within about one magnitude of the bright end of the giant branch and occurring in uncrowded regions of the cluster were studied. In all, six stars in M 3 and seven stars in M 92 were observed. The observations indicate that the brightest red giants in both clusters are variable, by amounts up to at least 0.15 mag. for the brightest star observed in M 92.

Three-color photoelectric and photographic observations of M 92 have been obtained by Sandage and Walker. The purpose of this investigation is to determine whether the red stars in the cluster are abnormally bright in the ultraviolet, as was found to be the case in NGC 4147, discussed in last year's report. Though the observations are not completely reduced, some preliminary reductions suggest that an ultraviolet excess is present in the red stars of this cluster.

A combined photographic and photoelectric calibration of the three-color system originated by W. Becker in Germany is in progress. Tifft is using a combination of observations made at the Harvard Observatory and at Mount Wilson. The system is to be applied to several open star clusters; the photoelectric effective wavelengths are at $\lambda\lambda$3750, 4750, and 5900, and the photographic wavelengths are very closely correlated.

Greenstein has continued to obtain relatively high-dispersion spectra of the red giants in M 13 and M 92. Exposures of two or three nights are required, at 18 A/mm. Successful exposures on the brightest stars in M 13 indicate that the spectra are relatively normal, except for weak *CN*. In M 92 all lines are enormously weakened as compared with those in M 13; the earlier classification of M 92 stars as F-type is incorrect in so far as line ratios or excitation is concerned. The hydrogen lines are very sharp and fairly strong; the metallic lines correspond to low temperature. Detailed spectrophotometry is in progress.

Deutsch has also continued the investigation of the spectra of globular-cluster red giants. Palomar coudé spectrograms at 38 A/mm have now been obtained for one or more stars in each of twelve clusters. Among all these, the red giants in M 92 have spectra with the most abnormally

weak metallic lines. The stars in M 15 come next in order of increasingly strong metallic lines. All the stars investigated show a very marked *CN* anomaly. In view of the absolute-magnitude difference Baum has found between the dwarf sequences in M 3 and M 13, it is particularly notable that the spectra on hand show the red giants to be indistinguishable as between these two clusters.

The spectra of a few more blue stars in the globular clusters M 13, M 10, and M 15 were obtained by Münch in the spring of 1955, using either the nebular spectrograph at Mount Wilson or the 8-inch camera of the Palomar coudé spectrograph. These spectra of population II stars are not radically different from those of similar stars of population I, although no star properly on the horizontal branch has been reached. The most striking difference from galactic B stars so far found is that the bright blue stars in globular clusters do not have detectable axial rotations.

White Dwarfs and Subdwarfs

Continued observations at Palomar by Greenstein have revealed several interesting new features in white-dwarf spectra. Some of the white dwarfs which had been classified as having continuous spectra have, in fact, very shallow hydrogen lines (HZ 43, LDS 678A). But another class seems to exist, typified by AC $+70°8247$, in which Minkowski and Kuiper had suspected the existence of other features. In this star an unidentified feature of λ4135 has been studied spectrophotometrically; it is asymmetric, about 200A wide, with a shortward core, about 50A wide, of 10 per cent central absorption. Other shallower, diffuse features may exist near λ3910 and λ4465.

Another peculiarity exists in the two known helium-rich white dwarfs, L 930-80 and L 1573-31; these both show the sharp displaced lines from metastable levels of neutral helium, λλ3889, 3965. Apparently ejection of matter is possible in spite of the enormous surface gravity. The sharp cores in H and K of *Ca* II previously observed in van Maanen 2 were found to exist also in L 745-46A, another F-type white dwarf. This unexpected evidence for instability in white dwarfs has support from observations of the hot subdwarfs.

Four subdwarfs of very early type have been studied by Greenstein, HZ 1, HZ 3, HZ 44, and HD 127493 (found by Münch during a search for interstellar lines in objects of high galactic latitude). They are all probably helium-rich. Sharp cores exist in λλ3889, 3965 of *He* I in all these objects. Strangely enough, these do not have large negative displacements. The sharpness of these metastable lines (found years ago by O. C. Wilson in absorption in the Orion nebula) can best be explained by either a detached shell or a very extended envelope surrounding the subdwarfs. Some unknown phenomenon (not rotation) produces this extension in the late stages of a star's evolution, and the same phenomenon may be carried to extremes in some white dwarfs.

A detailed theoretical analysis of HZ 44 and HD 127493 is being made by Münch and Greenstein. The spectra show very strong lines of *He* I, *He* II, *N* II, and *N* III.

Another interesting class of white dwarf or subdwarf shows an apparently composite spectrum. In hot blue stars, lines of *H*, *He* I, *He* II and shallow lines of *Ca* II, *Ca* I are combined. Examples are HZ 19, $-11°162$, and L 1363-3. These stars may be unresolved doubles, combining a K or M dwarf with a hot subluminous star. One particularly interesting case is HZ 9, a white-dwarf member of the Hyades cluster, showing strong hydrogen absorption lines, and emission lines of *H*, *Ca* II, *Si* I which may possibly arise in a dMe companion. Photoelectric colors are compatible with this hypothesis. Composite features may actually occur, however, in a single star; photoelectric colors of HZ 19 do not seem to establish duplicity.

A first analysis of the spectra of the F and G subdwarfs has been made by Greenstein. Palomar spectra at 18 A/mm were

available for 53 suspected subdwarf and high-velocity stars. A preliminary classification based purely on excitation temperature, using line ratios, was developed, insensitive to possible variation of the hydrogen-to-metals ratio. Within any class, the stars were next divided according to the strength of their metallic lines. It was possible to distinguish three groups: the ordinary "weak-line" stars, the "intermediates," and the "extreme weak-line" group. The mean tangential velocities for these groups were 57, 163, and 254 km/sec, respectively. Thus the spectroscopic peculiarity of weakness of lines increases as the space motion increases.

On the basis of published or new radial velocities, and using proper motions and the few available trigonometric parallaxes, an attempt was made to obtain the luminosities of the intermediate and extreme subdwarfs. In the mean, from A6 to G8, they are about $+2.0 \pm 0.3$ mag. below the main sequence, using the new spectral types. This estimate may be revised if color class rather than spectral class is used to define the main sequence.

The radial-velocity program is partly designed to detect spectroscopic binaries. So far only one star is established as a definite subdwarf binary, $-3°2525$, sdF3, (20C501); the six available plates show a maximum difference of only 18 km/sec, and the period is still unknown. Duplicity seems rare and rotation nonexistent among these subdwarfs.

Chemical Abundances and Structures of Stellar Atmospheres

On plates taken by Greenstein, P. W. Merrill has measured 1500 lines in the S star R Andromedae at its 1954 maximum. The dispersion of 4.5 A/mm in the blue and 6.8 A/mm in the red permitted more detailed investigation than has been heretofore possible. The presence of neutral and ionized rare earths, of heavy elements in general, and of neutral technetium (an unstable element) was confirmed. A very definite variation of velocity with excitation potential was established, negative displacements occurring for lines of low excitation potential. Greenstein is undertaking an abundance analysis of R Andromedae to evaluate the relative increase in the heavy-element content of the S star.

In collaboration with P. C. Keenan, of the Perkins Observatory, Greenstein has obtained spectra, in the red, of RW Cephei for comparison with other K supergiants. There seems little doubt that RW Cephei is one of the most luminous known stars of late type; the turbulence is very large, and the spectroscopic luminosity effects are extreme. The radial velocity of -61 km/sec places the star in a distant spiral arm, as does the complex structure of the interstellar D lines. One unexpected phenomenon is the doubling of low-level lines of a few ions, e.g., *Ba* II; a complex structure, probably including emission and displaced absorptions, is seen. These may be related to the emission lines observed by Wilson in the ultraviolet. The star must have a very large envelope.

Also in collaboration with Keenan, Greenstein is measuring on high dispersion the intensities of *CH* and *CN* lines in a group of late G giants of high and low velocities. In addition to the well-known weakening of the *CN* lines in population II stars, there are more complex phenomena. Some high-velocity stars have relatively strong *CN* and several stars show weak *CH*. Some variation in the abundance of carbon may exist in red giant stars.

Several faint and very distant B stars have been investigated by Greenstein. Surprisingly high radial velocities were found for $+28°4177$, MacRae $+29°$ Anon., and HD 172324, an A supergiant at high galactic latitude. HZ 22, a 13th-magnitude B3 star at the north galactic pole, proved to be a spectroscopic binary of large range, 160 km/sec. The existence of apparently normal B stars far from the galactic plane indicates that there may be a "high-velocity

tail" on the normal population I velocity distribution.

The emission-line star MWC 603, discovered by Vyssotsky, was found by Greenstein to have a complex emission spectrum. It is at galactic latitude 34°, has high velocity, −60 km/sec, and small proper motion. Tifft has measured several hundred emission lines, including *H*, *He* I, *He* II, *O* II, *O* III, *N* III, *C* III, and *Fe* II. The only forbidden lines are [*O* III] and [*Ne* III]. The underlying spectrum is about M3. It is an interesting symbiotic star; its faintness ($m_{pg}=11.7$) and consequent distance from the galactic plane are unusual.

John S. Mathis has studied measures in the spectra of the peculiar G star ζ Capricorni. He definitely identifies twenty-four elements, and possibly four additional ones; the ionized rare earths are extremely strong; *Cb* and *Cd* may be present. A search for transuranic elements was inconclusive.

W. K. Bonsack has studied the spectrum of HD 172324, which seems to be an A0 supergiant with the extraordinary velocity of −117 km/sec. The spectrum seems normal except for variable emission at *H*β, and some structure in *H*γ and *H*δ; these emissions are stronger than in α Cygni. The star is so far from the galactic plane that it may have evolved appreciably since its possible formation on transit through the plane.

John C. Stewart obtained and studied 10 A/mm spectra of the stars HD 37058, HD 37129 (two B3 peculiar stars in the Orion association), and HD 135485, a high-galactic-latitude object discovered by Münch to be peculiar. By developing an approximate theory of model atmospheres in the appropriate range of luminosity and gravity, he compared their atmospheres with those of standard stars. Stewart showed that HD 135485 has a considerably larger *He* abundance and a lower luminosity than the standard stars of the same effective temperature. A sizable *Ti* excess and *O* deficiency were detected in HD 37058. In these stars the only lines of *Ti* III that have thus far been classified were identified for the first time.

The visual companion of the M5 supergiant α Herculis is a G0 giant which Sanford has found to be a single-line spectroscopic binary of 52-day period. Recent coudé observations by Deutsch have now shown that in the spectrum of the G star there occur, besides the velocity-variable lines from its reversing layer, a set of stationary absorption lines. These lines arise from the ground levels of the most abundant atoms and ions; their contours and their velocities indicate that they originate in a shell far above the reversing layer. But Adams and McCormack discovered in 1936 that a similar set of zero-volt, violet-displaced shell lines occur also in the spectrum of the M star. In all probability, the same shell envelops both stars and produces the abnormal absorption lines in both spectra. Actually, the occurrence of zero-volt absorption cores is a feature of all M supergiant spectra, and has long been cited as evidence for the existence of very extended atmospheres around these greatly distended stars.

In the case of α Herculis, the diameter of the shell must exceed 1500 astronomical units or 1.6×10^5 solar diameters, in order that it may envelop the visual companion. Analysis of the spectrum indicates that, as Wilson has found for the chromosphere of ζ Aurigae, the envelope of this M supergiant is highly nonuniform, with most of the gas condensed in clouds that fill only about 10^{-7} of the total volume of the shell. The density within the condensation is probably of the order of 10^6 atoms per cm^3. The total mass of the shell is about 10^{-5} sun. The velocity of expansion is hyperbolic, and the M star is therefore losing mass at the rate of about 10^{-8} sun per year. In the light of current ideas of stellar evolution, these observations suggest that a K supergiant represents the ultimate quasi-steady state of a massive star that has evolved through the full sequence of shell-

source configurations. In the M supergiant stage that star then sheds mass at a rate that is appreciable on the evolutionary time scale. The subsequent configurations are unknown; we may speculate that the loss of mass proceeds until the star is able to come to equilibrium as a white dwarf.

Stellar Magnetic Fields

The gradual accumulation of data on the sharp-line peculiar A-type stars by H. W. Babcock now permits a preliminary magnetic classification of these objects into four closely related groups, depending on the main characteristics of the magnetic variation: (*a*) one-week magnetic reversers of large amplitude, (*b*) slower, quasi-periodic variables, (*c*) rapid irregular fluctuators, and (*d*) slow irregular fluctuators.

Group *a* consists of four stars that have much in common: α^2 Canum Venaticorum, HD 153882, HD 71866, and HD 125248. All are of spectral type Aop, all show reversing magnetic fields of very large and nearly identical amplitude that are periodic or nearly so, and their periods are remarkably similar, being 5.5, 6.0, 6.8, and 9.3 days respectively. This group is distinguished by the fact that no other magnetically reversing stars of very large amplitude are known. All four stars show the crossover effect, but in markedly different degree, and all except HD 153882 (which is probably slightly irregular) show synchronous intensity variations of the lines of *Eu* II and some other elements. The first- and last-named stars are well known as outstanding spectrum variables.

Group *b* at present includes 73 Draconis (A2p), β Coronae Borealis (Fop), and HD 188041 (Fop). The magnetic periods or cycles are, respectively, 20.3, 50:, and 226 days. We may speculatively include here the sun (G2) with its magnetic cycle of about 8300 days, for there is growing evidence that the hydromagnetic processes of the stars of magnetic groups *a* and *b* are similar in kind to that of the sun, though of much greater degree. The type star of group *b* is the well-observed magnetic and spectrum variable HD 188041, with a variable magnetic amplitude but regularly recurring minimum.

The majority of magnetic stars fall in groups *c* and *d*, which are characterized by irregular magnetic fluctuations, rapid and slow, respectively. Few of these stars show reversing fields, and none is a typical spectrum variable, although the spectra of all can be classified as peculiar. For most, the magnetic field intensity is not so great as for the stars of group *a*, but HD 133029 (Aop, group *c*) is an exception, showing a stronger field than any other star investigated. Group *c* now includes six stars, group *d* eight or more. A number of others remain to be classified after further observation.

In passing along the regular or cyclic sequence from group *a* to *b*, and also along the parallel but irregular sequence from *c* to *d*, the following systematic effects are noted: The rate of magnetic variation progresses from rapid to slow; the spectral types progress from earlier to later (Aop to Fop); the magnetic amplitude shows a general decrease; and the line widths show a progression from "sharp" to "ultra sharp." (Stars with lines appreciably broadened by axial rotation have been automatically excluded, since the Zeeman effect cannot be measured in them.) These relationships are all compatible with the view that hydromagnetic turbulence contributes materially to line broadening; that the stars investigated are observed essentially pole-on, having been selected on the basis of line sharpness from the far greater population of "normal" A-type stars; and that in a minority of the stars with strong fields a co-ordinated magneto-hydrodynamic cycle may obtain, which reaches a peak of amplitude and regularity when the period is approximately one week. By inference, strong magnetic fields are ubiquitous among stars of spectral type A, but perhaps absent in those of spectral type B because of the lack of hydrogen convection

zones. This hypothesis enhances interest in the regenerative dynamo theories of stellar magnetism, which require axial rotation plus the effect of Coriolis forces on convective material.

On 71 spectrograms obtained over a six-year period, the sharp-line star HD 133029 has invariably shown a strong magnetic field of positive polarity, at maximum reaching $H_{eff}=3600$ gauss ($H_p=10{,}800$ gauss). Fluctuations of about 25 per cent have been observed in one day, and notable changes are indicated within a few hours. Slow fluctuations are also found. Since the primary field is presumably dipolar, the aspect of the star is in all probability essentially pole-on, both rotationally and magnetically. The irregular magnetic fluctuations most plausibly arise in association with hydromagnetic turbulence in and near the photosphere.

Periodic spectrum variation or magnetic-field variation is now recognized in 13 peculiar A stars. Among these stars, all but one have line widths that have been interpreted on the hypothesis that each star rotates with the observed period about an axis nearly normal to the line of sight. The only star that appeared to violate this period-line-width relation was 21 Comae. Earlier work had indicated a period of 7.75 days for this object, but its line widths seemed to require a period of 1.5 days or less. Coudé spectra taken by Deutsch have now shown that the period is actually 1.0256 days. The star is therefore no longer seriously discordant with the period-line-width relation.

Photoelectric Standards

Many astronomical problems, including all distance measures beyond the range of direct trigonometric methods, depend on the measurement of apparent brightness. Until recently, these photometric results have rested upon photographically derived magnitude scales. Photoelectric data now reveal that these photographic scales were sometimes in error near the telescope threshold by as much as a whole magnitude, which corresponds to a factor of more than 2 in brightness. It is consequently important that photometric work on faint objects, such as that bearing on the determination of cosmic distances, either be done photoelectrically or be referred to photoelectrically established magnitude standards.

Much of the photoelectric work carried out by Baum during the past five years has been concerned with the setting up of photoelectric standard magnitude sequences. This program has now been completed, and the results are being assembled for publication. These standard sequences

TABLE 3

Selected Area	R.A.	Decl.	No. of stars	Magnitude range
68.....	$0^h\ 14^m$	+15°	65	9–23
94.....	2 54	0	41	9–18
71.....	3 15	+15	37	9–19
51.....	7 28	+30	57	10–22
54.....	10 27	+30	42	8–18
57.....	13 06	+30	52	9–23
107.....	15 37	0	40	8–19
61.....	17 01	+30	46	9–19
89.....	21 11	+15	43	9–20

are located in nine selected areas distributed around the sky in such a way that one or two of them are always within easy reach for making photographic transfers. Though this transfer procedure does not lend itself to high precision, it avoids systematic errors in the magnitude scale itself and it provides an efficient method for the approximate photometry of distance indicators in near-by galaxies.

The new photoelectric standard sequences are located in nine Kapteyn Selected Areas. The position of these selected areas and the number and magnitude range of the stars measured in each are given in table 3. The seven areas at +15° and +30° declination form a belt around the northern hemisphere, and are spaced 3 to 4 hours apart. The belt is lopsided

($+15°$ declination on one side and $+30°$ on the other) in order to dodge the Milky Way, which would be too crowded a region for good standard sequences. The two areas at the equator (zero declination), one available in the autumn and the other in the spring, are intended for observers in the southern hemisphere.

In each area most of the sequence stars lie within a circle 15′ in diameter. Most of the data in the 9 to 19 magnitude range were obtained at Palomar during 1951 and 1952, using a refrigerated photomultiplier, a sensitive d.c. amplifier, and a strip-chart pen recorder. The sequences were intercompared with one another and ultimately with the North Polar Sequence, which was adopted for defining the International color system and the zero point of the magnitude scale.

The development of photon-counting techniques by Baum in 1953 has made it possible for him to extend photoelectric photometry to objects at the photographic limit of the 200-inch telescope, which was found by this method to be around the 23d magnitude. Although it has even been possible to observe photoelectrically objects which are too faint to be photographed, one must ordinarily depend on photographs for selecting objects to be measured photoelectrically and for determining their locations relative to brighter stars so that the photometer can be correctly aimed at them.

All the standard-sequence stars, bright and faint alike, were measured in two colors (blue and yellow), and the data were corrected in the conventional way for atmospheric extinction and instrumental effects. Mrs. Coffeen, A. M. Gehrels, and R. L. Newburn assisted with the computations. The final results are expressed as photovisual magnitudes and International color indices.

Other Studies

To test certain current ideas of stellar evolution, an analysis was made by Sandage of the extensive data published by A. Slettebak, of the Perkins Observatory, on the rotational velocities of stars in the M_{bol}, log Te plane. The axial rotations of all stars not now on the main sequence were found to be consistent with the idea that these stars were once main-sequence objects but have moved into the giant and supergiant region by an evolutionary process. In particular, the data are entirely consistent with the evolutionary tracks for type I stars computed by Dr. M. Schwarzschild and his collaborators.

The stars ρ Leonis, HD 119608, and HD 214080 are of B1 I*b* according to the W. W. Morgan classification. Other stars at high galactic latitudes have luminosities considerably above the main sequence. From their known distance and radial velocity, for any reasonable cross motion assumed, it is found by Münch that these stars left the galactic plane from 3 to 5×10^7 years ago, an interval which is longer than their lifetime as B1 I*b* stars. Thus when they left the galactic plane they were not B1 I*b* stars, but something else (possibly O stars). On the other hand, on the basis of the kinematics of the expanding association around ζ Persei it has been stated by Oort and others that the members of this association were formed 2×10^6 years ago. As far as is possible to ascertain by visual inspection of their spectra, ζ Persei has a spectrum and luminosity nearly identical with those of the three stars mentioned above. The difference in order of magnitude in the lifetimes calculated for B1 I*b* stars by the two methods leads to the conclusion that either a star may reach the B1 I*b* stage by two entirely different evolutionary tracks in the Hertzsprung-Russell diagram, or ζ Persei was not formed when the expansion of this association began. To formulate these propositions more precisely, a photometric comparison of large-dispersion plates of the stars involved has been undertaken by Münch.

The visual magnitudes of the components in 157 double-star systems were measured by Pettit in the years 1945–1947

with the wedge photometer at the 60-inch telescope. Systems with close components having large difference of magnitude were chosen. These have been reduced on the basis of a laboratory study of the properties of the photometer. The average deviation (o−c) for 67 stars which are in the Harvard Photometry is +0.07 mag.; for 86 stars which are in the BD catalogue, it is +0.14 mag. Deviation of the faint components from the Aitken Catalogue values reaches 2 mag. in only 4 cases.

At the request of Miss Sarah L. Lippincott, of the Sproul Observatory, Baade searched at the 200-inch during the early spring months for the faint companion of Ross 614 whose orbit had been derived from the periodic motion of the main star. The companion was seen in the predicted position as a star of about the 15th magnitude on March 24, 1955, and immediately photographed. The final evaluation of the data at the Sproul Observatory showed that the companion of Ross 614 is the star of smallest mass now known (0.08 solar mass).

GASEOUS NEBULAE AND INTERSTELLAR MATTER

Internal Motions

The study of the internal motions in planetary nebulae has been continued by Wilson using a multislit attached to one of the coudé spectrographs. An attempt was made to investigate some of the fainter irregular nebulae, using the strong Hα line. However, the overlapping of multislit patterns of the near-by [N II] radiations at λλ6548 and 6584 introduced such confusion that definite interpretations were not feasible.

On the other hand, multislit spectrograms of several bright planetaries in the photographic region, made at Palomar with the 6-foot camera (4.5 A/mm), have proved to be of considerable interest. Comparison has been made with lines calculated on the assumption of an ellipsoid of revolution viewed at an angle of 45° with the major axis. This comparison lends strong support to the view that the more regular planetaries are ellipsoidal and owe this characteristic to the fact that the velocities in the nebular shell are not everywhere the same. It seems likely that the outward velocity varies in a fairly regular fashion with direction from the nucleus, so that where the velocities are larger, the matter has traveled farther, and vice versa.

The technique for obtaining multislit plates of the Orion nebula in order to study the fine structure of its internal motions has been modified by Wilson and Münch from that used in previous years. The arc comparison spectra are now recorded at the four corners of the slit pattern instead of at the two ends of the central slit. This method provides the calibration data necessary for an accurate reduction of the measures of the nebular lines. Plates have been taken of several fields in the Orion nebula with this procedure. These are now being reduced.

Nebular Spectra

Observations of nebular spectra for the purpose of fixing the wavelengths of the forbidden lines have been completed by Bowen for the wavelength range from 3300 to 8500A. The wavelengths of 88 lines emitted by the ions *N* I and II, *O* I, II, and III, *F* IV, *Ne* III, IV, and V, *S* I, II, and III, *Cl* III and IV, *A* III, IV, and V, *K* IV and V, *Ca* V, *Mn* V and VI, and *Fe* III, V, VI, and VII have been measured with dispersions from 9 to 57 A/mm. Where possible the lines have been observed in several nebulae in order to reduce errors arising from differential velocities between ions emitting permitted and forbidden lines. It is believed that accuracies have been attained ranging from 0.02A for the strong lines observed with the highest dispersion in several objects to 0.3A for very faint lines observed in only one object.

In order to provide a definitive list of the wavelengths and intensities of the lines

emitted by NGC 7027, the low-dispersion plates with intensity calibration taken by Minkowski and Dr. L. H. Aller, of the University of Michigan Observatory, have been combined with the high-dispersion plates taken by Bowen for the program on wavelengths of forbidden lines. A total of 263 lines were observed. One of the surprising features of this spectrum is the great development of the 4F–nG and 5G–nH series of *He* II, which were observed to n=29 and n=40, respectively.

Densities in Nebulae

According to the theoretical work of Seaton in England, the intensity ratio of the two components of the $\lambda 3727$ emission line of [*O* II] varies with the electron density in a way which can be calculated. A measurement of this intensity ratio in an object therefore gives directly the density in that object, and since the line appears in all interstellar emission regions and in many planetary nebulae, it provides a powerful tool for obtaining information about the physical state of these objects. Osterbrock measured this $\lambda 3727$ intensity ratio at a number of points in the Orion nebula as a check on the theory, for in this nebula the sharp decrease of surface brightness from the center outward shows that there is a marked decrease in density from the center outward, which should also be observed as a variation of the $\lambda 3727$ intensity ratio from the center outward. These observations in the Orion nebula did in fact agree with the theory. The densities found from these observations range from a high of about 3×10^4 electrons per cm^3 at a point near the Trapezium to a low of about 3×10^2 electrons per cm^3 at the faintest points observed.

Osterbrock also measured this ratio in a number of planetaries of low surface brightness in order to find the densities in these objects. Among the objects so far observed, the densities range from about 2×10^3 electrons per cm^3 in NGC 3242 to about 1×10^2 in NGC 3587. Spectra have also been obtained for measurement of this intensity ratio in the filamentary nebula IC 443, in the rim of the "comet-shaped object" in NGC 2264, and in a number of normal *H* II regions.

Nebulae and Emission Stars in the Southern Hemisphere

A study of the plates taken on the University of Michigan Expedition to the Southern Hemisphere with the 10-inch astrograph of the Mount Wilson Observatory has been continued by Henize. Catalogues and charts of 236 emission-line stars and 532 emission nebulae in the Magellanic Clouds have been prepared for publication. Fifty-one of the 68 short-exposure plates of the southern skies have been searched for bright emission stars in the 3.0 to 9.0 magnitude range.

Interstellar Absorption Lines

Observations of interstellar absorption lines have been continued by Münch in distant stars both in the Milky Way and at high galactic latitude. The observations of stars in the northern Milky Way are now essentially completed, and the data derived from them have been studied. Besides the formerly announced structural features of the galactic system (spiral arms), the observations indicate considerable variations, along the spiral arms, of the velocity distribution of the interstellar gas clouds. Stars seen across volumes of space bordering on large *H* II regions show generally more high-velocity components in their interstellar lines. The stars in NGC 2244, for example, show up to three high-velocity components. Although to derive the shape of the velocity distribution in various regions would require more extensive material than is now available, there can be no doubt that the elongated features pointing toward the sun derived for the density distribution of interstellar hydrogen by analysis of the 21-cm line are due entirely to variations in the velocity dis-

tribution of the clouds. There also seems to be a systematic dependence of the shape of the velocity distribution on position across the spiral arms, in the sense that high-velocity clouds seem to be more frequent in regions near the edge of spiral arms, where the over-all mean density of diffuse matter is lower.

The discovery of multiple interstellar lines in stars high above the galactic plane has raised interesting questions regarding the life and stability of interstellar clouds; observations show that clouds may exist up to 1 Kpc above the plane. Their interstellar lines occur with velocities of either sign, with about the same frequency and intensity. Were interstellar clouds expanding freely into vacuum, as Oort has pointed out, we should expect to find most of the clouds with receding velocities, since in the time (of the order of 4×10^7 years) a typical high-velocity cloud takes to return to the plane, it would diffuse to extremely low density. Since the observations do not substantiate this expectation, the question arises whether the clouds are held together by some force, probably of a magnetic nature. The scarcity of early B stars at high galactic latitude makes additional observations difficult, but an attempt is being made to observe fainter late B stars accessible with the 10 A/mm dispersion.

GALAXIES

The Andromeda Nebula (Messier 31) and Other Members of the Local Group

Baade has practically completed his program for the study of the stellar population of the Andromeda nebula. Miss Swope finished the determination of the light-curves of the variables in the previous three fields (see last year's report) and began the investigation of the variables in the outlying fourth field, at 96′ south preceding the nucleus. This field is crossed by one of the outer and poorly populated arms of M 31. The total number of variables (about 60) is correspondingly much smaller than in the previously studied fields. But since the field is essentially free from absorption, it is expected to furnish the final value for the distance modulus of the Andromeda nebula. In spite of the large distance from the center of the nebula, population II pervades the field in amazing richness. Since on 103a-D plates behind a GG-11 filter stars of photovisual magnitude 22.7 can be reached at the 200-inch telescope in exposure times of 75 minutes, stars of population II down to the absolute photovisual magnitude -1.5 are easily accessible in this field. A search for variables among these brighter population II stars was so successful—the blinking of only two pairs of photovisual plates led to the discovery of 56 new variables which were beyond the reach of the blue-sensitive plates of the earlier series—that it was decided to supplement the photographic survey of this field with a photovisual one. Most of the new variables should be stars of intermediate and large color indices. It is expected that their study will furnish important clues for the identification of the inter-arm population in our own Galaxy.

An attempt by Baade to identify the brightest planetaries among the population II stars of this same field also proved successful. The following plate and filter combinations were used: (1) a 103a-D plate behind a GG-11 filter, recording range from $\lambda 4900$ to $\lambda 6400$; this range includes the green nebular lines; (2) a 103a-D plate behind a Corning 3484 filter, recording range from $\lambda 5200$ to $\lambda 6400$; the green nebular lines are cut off; the remaining range contains only relatively weak emission lines.

Intercomparison of the plates in the blink comparator led to the discovery of 4 planetary nebulae. Their images, which appear of course perfectly stellar, are strong on the first plate-filter combination but absent on the second. All four could be identified on blue-sensitive plates for which the photographic magnitude scale is avail-

able. Their mean photographic brightness is $m_{pg}=22.0$. The corresponding absolute photographic magnitude -2.2^m is in excellent agreement with the value previously derived by Louis Berman for the planetaries of our own Galaxy.

Additional plates have been taken by Baade for his program on the variables in pure type II systems of the Local Group. Observations of the Draco system were finished during the past year. On about half of the plates Miss Swope has already measured the variables at the Eichner photometer. For both the Leo and Ursa Minor systems another season will be required before the necessary plate material can be collected. In all three systems the search for variables kept step with the growth of the plate material.

Between June 1953 and January 1955 Arp made observations of the Andromeda nebula (M 31) on 290 nights for the purpose of obtaining statistical data on ordinary novae. A study of the plates taken resulted in the discovery of 30 novae. The fastest were of 5 days' duration (duration defined as the period during which the nova is brighter than $m_{pg}=20.0$) and reached a magnitude of 15.7; the slowest were of 150 days' duration and reached $m_{pg}=18.0$. Close relations between duration, rate of decline, maximum magnitude, and integrated energy of outburst were found.

The shape of the subsystem comprising the novae, including their radial distribution, was computed. It is indicated that the novae either shine undimmed through the nebula or are almost completely blocked by a dust lane. After correction for these factors, the final frequency of novae in M 31 is found to be 26 ± 2 novae per year.

Assuming the present distance modulus of M 31, 24.2, the absolute magnitudes of these novae are in nearly exact accordance with luminosities of well-determined galactic novae. Light-curves and outburst energies are also strictly comparable.

During this same period a somewhat less exhaustive search was made for novae in M 32, NGC 205, M 33, NGC 147, and NGC 185, but none were found.

Velocities and Distances of Galaxies

The catalogue of red shifts for 620 extragalactic systems has been completed by Humason. This catalogue contains the red shifts of all galaxies measured at Mount Wilson and Palomar since the beginning of the program in 1928. Included in the catalogue are red shifts for 26 clusters. These clusters provide the data for the deepest penetration into space, because they represent the greatest distances attained for a given apparent magnitude. For the convenience of workers in this field, the red shifts of 300 galaxies observed by Dr. Nicholas Mayall at the Lick Observatory are included with Humason's data. These combined catalogues provide the entire body of red-shift data now available, upon which evaluation of the expansion properties of the universe rests.

The magnitudes and colors of 561 extragalactic systems on Humason's list were published during the year by Pettit. Many of these were measured with several aperture plates. For 127 galaxies the nuclei were also measured. The trend of the E types corresponds to the formula C.I.$=$ 0.04 $(m_{pg}-9$ mag.$)+0.84$ mag., and of the S types to C.I.$=0.08$ $(m_{pg}-9$ mag.$)+0.50$ mag. Among the by-products was a determination of the magnitudes and color indices of the central stars in the Selected Areas of the 30° zone and a number of stars in the Polar Sequence.

These data on velocities and magnitudes permit a complete rediscussion of the red-shift–magnitude relation for both field galaxies and clusters of galaxies. The Mount Wilson–Palomar red-shift catalogue, the Lick catalogue, and the rediscussion by Sandage will appear in one paper. The combined data suggest the following five major conclusions:

1. The slope of the correlation line of m_c vs. log c $\Delta\lambda/\lambda_0$, both for field galaxies

and for the great clusters with $\Delta\lambda/\lambda_0 < 0.1$, is as close to 5 as the probable errors of the determination. Here m_c is the apparent magnitude measured photoelectrically but corrected for the variable photometer apertures used by Pettit and for the selective effect of red shifts. This result means that for small $\Delta\lambda/\lambda_0$, the red-shift–distance relation is linear, on the supposition that there is no general internebular obscuration. If a general uniform internebular absorption is postulated, then the red-shift–distance relation is nonlinear even for small $\Delta\lambda/\lambda_0$. The absorption must be of just the amount required to cancel the nonlinearity of the red-shift law, so that the observed [m_c, log c $\Delta\lambda/\lambda$] relation remains linear. Such an interpretation is highly unlikely but cannot be definitely excluded.

2. The *departures* from uniformity for any postulated intergalactic obscuration must be distributed with a dispersion of $0.3 > \sigma > 0$ mag. This conclusion comes from a study of the residuals of the individual cluster points from the [m_c, log c $\Delta\lambda/\lambda$] relation.

3. The apparent expansion appears to be isotropic.

4. The cluster data for $\Delta\lambda/\lambda_0 > 0.1$ show an apparently significant departure from linearity in the direction which indicates deceleration, according to theoretical equations given by Robertson. Because of the cosmological significance of this last result, the accuracies of the various quantities which lead to it are being examined. The presence of any internebular obscuration will strengthen the conclusion. The analysis suggests that any reasonable estimates of (*a*) the errors in the measured magnitudes, (*b*) the rate of change of the absolute bolometric magnitudes of galaxies due to evolution, and (*c*) the consequences of the Stebbins-Whitford effect require a decelerating universe. This result cannot be regarded as established, however, until an adequate theory is available to explain the Stebbins-Whitford effect.

5. The Hubble red-shift parameter H is provisionally evaluated (*a*) from the magnitudes of resolved stars in NGC 4321 that have been isolated from the emission *H* II regions, and (*b*) from the assumption that the brightest field and cluster galaxies are giants of luminosity comparable to that of the Andromeda nebula, with the result that $H = 180$ km/sec per 10^6 psc.

Spectroscopic observations of the colliding galaxies responsible for the Cygnus radio source were made by Minkowski and Wilson for the purpose of testing the constancy of $\Delta\lambda/\lambda$ for the nebular red shift. The velocity of this object is nearly 17,000 km/sec, and over the range from $\lambda 3426$ of [*Ne* V] to *Hα* and the near-by [*N* II] lines it is found that $\Delta\lambda/\lambda$ is constant within less than 0.1 per cent.

An investigation of M 87, which is a giant E0 galaxy in the Virgo cluster, has been carried out by Baum. This galaxy has an extraordinary number of globular clusters, about a thousand of them being known that are brighter than $m_{pg} = 23.5$. The projected distribution of these clusters was investigated by counting their images on a 200-inch plate in contact with a finely ruled réseau. After corrections for images belonging to the general field and for a change-of-threshold effect toward the nucleus, the number of globular clusters per unit area in M 87 was found to decrease approximately as $1/r^2$ from the nucleus.

The globular clusters belonging to M 87 also provide means for determining the distance of the Virgo cluster of galaxies. By comparing the globular clusters in M 87 with those in the Andromeda galaxy (M 31), one estimates the modulus of M 87 to be 30.2 magnitudes.

Baum has continued the photoelectric program for determining the distances of galaxies beyond the range within which the usual distance indicators can be resolved. This program involves the photoelectric intercomparison of apparent luminosities, apparent diameters, and spectral-energy distributions of the galaxies themselves. First attention is being given to E0 galaxies belonging to clusters of galaxies having known red shifts, the closest being

the Virgo cluster, which is near enough to be reached by distance indicators. Work on this program during the report year also included four sets of observations on two moderately distant clusters whose red shifts are roughly 20,000 and 40,000 km/sec.

As a first step in this program, accurate data were obtained for the distribution of surface brightness in M 87, which is one of several relatively near E0 galaxies. These observations in M 87 have been carried out as far as 35 kiloparsecs from the nucleus, farther than for any other galaxy. At large radii, the surface brightness is found to be falling off approximately as $1/r^2$, and therefore the volume density of stars is decreasing as $1/r^3$. This is the same as the rate of decrease in the volume density of globular clusters noted above. The integrated apparent luminosity is accordingly increasing as log r, and shows no tendency to converge toward any asymptotic "total magnitude." Thirty-five kiloparsecs is an appreciable fraction of the distance between M 87 and neighboring galaxies within the cluster. Unless the thinning out of stars undergoes an unexpected change of character at still larger radii, one must conclude that cluster galaxies simply blend into one another with no empty intergalactic regions between. Each galaxy is bounded only in the sense that the domain in space which can be allotted to it is finite.

A qualitative confirmation of this picture was obtained from some photoelectric surface-brightness measures of the seemingly "vacant" regions between galaxies in Cl 0925+2044, which is a remote cluster with a red shift of 57,000 km/sec. These data revealed that intergalactic population was very much denser within the cluster than in regions outside the cluster, as would be expected for a cluster of objects having roughly log r divergences. As a result, the total luminosity of this cluster is about double that which one would conventionally estimate by adding up the photographically estimated luminosities of its individual members.

Clusters of Galaxies

The extensive program on the statistics of clusters of galaxies was continued by Zwicky. The distribution of about one thousand clusters of galaxies was investigated, using about 30 plates taken with the 48-inch schmidt, covering 40 square degrees each. Only 8 distant clusters were counted on the plate covering the Coma cluster. In the regions occupied by the Virgo cluster about 15 to 20 distant clusters are recognizable, whereas in areas not containing any near-by clusters 40 to 70 distant clusters are recognizable per plate (14×14 inches). These observations lead Zwicky to the conclusion that within the large clusters of galaxies there occur local accumulations of dust which dim the light traversing them by as much as 0.5 photographic magnitude.

Large spherically symmetrical clusters of galaxies were found to have constant characteristics independent of distance, except for the apparent range of colors of their member galaxies, which increases with distance.

The statistical investigation of the distribution of cluster centers shows that there is no systematic clustering of clusters. Any apparent superclusters such as those in Corona Borealis and in Perseus-Pisces must be considered accidental in the sense of being expected in the proper frequency in a random distribution of noninteracting objects.

The luminosity function of the member galaxies of the one thousand clusters mentioned above was investigated by Zwicky. In agreement with his previous findings, the luminosity function is found to be an exponential function which increases monotonically with decreasing brightness of the galaxies and shows no maximum.

Investigations on the luminous intergalactic matter within the large clusters of galaxies have been continued. More photographic evidence has been obtained by Zwicky for more than a dozen clusters at various distances in which such matter, both blue and red in color, exists with a

surface brightness in the range $m_{pg} = +23$ to $+25$ per square second of arc.

The Large-Scale Distribution of Individual Galaxies

About four million galaxies have been counted by Zwicky and his collaborators during the past nineteen years on plates obtained with the 18-inch and 48-inch schmidt cameras as well as with the 100-inch and 200-inch reflectors. The statistics of these counts in depth and in breadth have led Zwicky to preliminary conclusions concerning the large-scale distribution of matter in space and the existence of intergalactic dust. Most important in these investigations are the 48-inch schmidt plates. With the completion of the Sky Survey next year, the 48-inch will be available, and a large-scale program in co-operation with the Lick Observatory group has been initiated. This program will supplement the Lick program of nebular counts by Drs. C. D. Shane and C. A. Wirtanen, which has been in progress for the past decade. The Lick observers will continue their program of counting on plates taken with the 20-inch and 5-inch Ross lenses, while Zwicky and his assistants will count galaxies on 27 fields photographed with the 48-inch schmidt telescope. The fields agreed upon cover the areas from R.A. 12^h to $14^h\ 4^m$ and Decl. $+5°$, $+10°$, and $+15°$. Each field will be photographed on Eastman 103a-O emulsion with exposure times of 4 and 14 minutes and on Eastman 103a-E emulsion behind a red filter with exposure times of 16 and 48 minutes. Each plate will be counted as subdivided into 1296 squares of $10' \times 10'$ area. Counting techniques of the Mount Wilson and Palomar Observatories and the Lick Observatory groups were intercompared by interchange of observers during the report year.

Photographic Photometry of all Galaxies Brighter than about Photographic Magnitude +15

This program, which was started by Zwicky and continued by Emil R. Herzog and Wild, has resulted in the issuing of a first catalogue of about 1200 galaxies as a report to the Office of Naval Research. All together about 7000 galaxies have been measured for position and for photographic magnitude, mostly covering the belt between R.A. 8^h and 17^h and Decl. $0°$ to $+20°$. These measures are being reduced by Herzog and Wild in Switzerland, while Zwicky with the help of a computer has started the work on new nebular fields outside the belt mentioned.

Stellar Content of Individual Galaxies

A new method has been developed by Zwicky for the study of the stellar content of individual galaxies based on color differences. A positive of a photograph taken in one color is superposed on a negative exposed to another wavelength range. By an appropriate choice of the wavelength ranges to which the original negatives are exposed, the distribution of the stars of a particular color type may be revealed over an entire galaxy. For instance, in the case of Messier 51, the yellow stars in the spiral arms are arranged in a surprisingly smooth and streamlined array, whereas the blue stars form a very irregular pattern. Objects of similar color classes can be segregated and their relative spatial distributions can be recognized at a glance, even though several color classes may be intermingled and occupy the same space. The method of composite photography has likewise been used for the analysis of the degree of polarization of light from various regions of distant galaxies.

Interconnected Multiple Galaxies

A great number of structural types of connection between the members of multiple galaxies has been investigated. It is estimated by Zwicky that on the 48-inch schmidt survey there appear some three thousand double and multiple galaxies which are interconnected and separated by more than 1 and less than 20 apparent diameters of the member galaxies. As better photographic records are obtained, the lu-

minous matter connecting and surrounding many multiple galaxies is found to cover ever larger areas. For instance, in the nebula NGC 750-751 a very long extension from one of the member galaxies was found.

RADIO SOURCES

The Radio Source in Cassiopeia

The Cassiopeia nebulosity has been under observation at the 200-inch since 1951. It soon became evident that the diffuse condensations which form the northern arc of the nebulosity show a systematic outward motion. At the blink comparator Baade has recently measured these motions on two plates with a time interval of 3.29 years. All together, the motions of 22 condensations were measured. The resulting picture is that of a remarkably regular expansion from an origin which coincides closely with the previously adopted center of the radio source. The mean annual transversal motion amounts to 0.367 second of arc. Combining this value with the present mean angular distance of the condensations from the center and assuming a constant rate of expansion, one gets the date for the beginning of the expansion as some 300 years ago.

Spectroscopic observations of the Cassiopeia source have been continued by Minkowski. More than 60 condensations have now been investigated. The radial velocities show clearly the difference between the sharp filaments, which show no observable motions and have radial velocities from 0 to −300 km/sec, and the diffuse condensations, which show the large motions observed by Baade and have radial velocities ranging from −4000 to +4900 km/sec. The systematic expansion of the diffuse condensations, which is now safely established by the observed motions, cannot be recognized in the radial velocities, which appear highly irregular. The increased number of observed condensations now available, however, reveals the curious fact that neighboring condensations are not independent with regard to their radial velocities. At least five localized groups of condensations can be recognized which have distinctly different mean radial velocities with relatively small internal scatter. The nebulosity thus seems to consist of a number of clouds each of which contains a certain number of the visible diffuse condensations.

A possible interpretation of the observations is that originally the nebulosity was a symmetrically expanding mass located in or near interstellar clouds. The individual clouds of the present nebulosity may be surviving parts of the original mass which have penetrated regions of relatively low interstellar density. Their still persisting outward motion may, however, have been slowed down by interaction with the interstellar material. The sharp filaments may have been formed by the interaction of the expanding mass with interstellar material of higher density; the observations leave the question open whether they are fragments of the expanding mass which have almost entirely lost their outward motion or whether they represent effects produced in the interstellar material by the stopping of the expanding mass.

A determination of the distance of the object from transverse motion and radial velocity is not possible, since the directions of the space motions of the individual clouds are not known. The distance can, however, be determined from the random motions and velocities of the condensations within individual clouds. On the assumption that the random space velocities have a spheroidal distribution, the distance is found to be 540 ± 150 parsecs, as calculated from three different clouds each of which contains an adequate number of condensations with measured motions and radial velocities.

The question as to the nature of the object is difficult to answer. The original velocity of expansion must have been 5000

km/sec or more, much higher than in ordinary novae or in supernovae of type I as exemplified by the Crab nebula, which has a velocity of expansion of only 1100 km/sec. The only known objects with velocities of the required order are the supernovae of type II. The apparent magnitude of such a supernova should have been about zero, if a value of 5 to 6 magnitudes is assumed for the interstellar photographic absorption; such a value is suggested by the relative intensities of certain lines in the spectra of the condensations. No nova has been observed near the position of the Cassiopeia source within the past 300 years.

The Colliding Galaxies NGC 1275

Although colliding galaxies are safely established as radio sources, we have at present little information about the details of such collisions. The strongest radio source of this kind, Cygnus A, is not very suitable for detailed investigation because of its great distance. A much better subject is the colliding pair NGC 1275 in the Perseus cluster of galaxies. Here an early-type spiral is in collision with a late-type spiral and the pair is close enough to show much structural detail on plates taken at the 200-inch telescope. An examination of the existing plates convinced Baade that it should be possible to localize the regions of the colliding gases on exposures with suitable plate-filter combinations if in such "hot spots" the total light emitted by the colliding gases were of the same order as the continuum of the unresolved stars. Attempts thus to localize the hot spots by their $H\alpha$, [*O* III], and other emissions were successful, and a detailed picture of the emission regions was obtained.

The spectroscopic investigation of these spots by Minkowski led to the following results: In the northern part of the object the emission lines are double, showing a velocity of +5200 km/sec for the early-type spiral and of +8200 km/sec for the late-type spiral. The emission spectra of both nebulae consist of strong [*O* II] lines and weak lines of hydrogen. In the southern part an entirely different type of spectrum appears, showing one set of asymmetrical lines of considerable width, indicating a velocity of +5200 km/sec. *H* lines and forbidden lines of *O* I, *O* II, *O* III, *Ne* III, and *S* II appear. This spectrum appears superposed on the nucleus of the early-type spiral where it was first observed by Humason many years ago. But it is not restricted to the nuclear region, as happens in certain spirals with bright semistellar nuclei, and it appears with somewhat less intensity farther to the south.

The appearance of the object and the spectroscopic observations suggest the interpretation that the late-type spiral is inclined against the early-type spiral in such a way that in the north the late-type spiral is in front. Moving toward the early-type spiral, it has penetrated the other system in the center and south of it, where now highly excited gas with large internal motions shows the aftermath of the collision. The velocity of the mixed gas is close to the velocity of the early-type system; this requires that the early-type system be the more massive one, a conclusion which is supported by the general appearance of the two galaxies. The actual collision is in progress to the north, where the gas masses of the two spirals can still be seen separately. A more detailed discussion of the collision suggests a duration of the order of a million years; more than half this time has passed, and the effects of the collision should now be past their maximum.

NATIONAL GEOGRAPHIC SOCIETY—PALOMAR OBSERVATORY SKY SURVEY

Three hundred and thirty-one pairs of plates were taken for the Sky Survey during the report year. Of these 243, or 73 per cent, were acceptable. This is the largest number of acceptable plates obtained in any one year since the survey started.

Acceptable plates were available at the end of the year for 803 of the 879 fields required to complete the survey. All the summer fields have been taken, and it is anticipated that the winter season of 1956 will see the completion of the survey.

The limiting magnitude of the sky-survey photographs has been determined from five pairs of plates which include Selected Area 57. The calibrations are based on measures of faint stars made by Baum at the 200-inch telescope with the photon counter. The blue survey photographs of average or higher quality record all stars of photographic magnitudes brighter than 21.1. The red plates record stars of red magnitudes brighter than 20.0. The red magnitudes here are very close to those of Kron and Smith. Stars of International color index about 0.7 appear equally bright on the blue and red survey photographs.

Two comets were discovered on the sky survey during the year, Comet Harrington-Abell (1955a) on March 22, and Comet Abell (1955b) on April 13. One fast-moving asteroid (daily motion about 2°) was discovered on December 17. Unfortunately, however, inclement weather immediately following its discovery prevented further observations of this object, and it was lost.

Catalogues and descriptions are being compiled of some of the many new objects which have been discovered on the survey plates. One list includes a large number of clusters of galaxies. A second list includes thirteen new globular clusters, six of which are very distant; the other seven lie close to the galactic plane and most of them are so heavily obscured that they are almost invisible on the blue plates.

Seventy-two new planetary nebulae have also been discovered. These comprise a group of objects of low surface brightness and large angular diameter. Because of their low surface brightnesses, most of them must be intrinsically large, and hence are among the largest and probably the oldest planetaries known.

Orders for nearly a hundred copies of the Atlas have been received. At the end of the report year the printing of the first section of the Atlas, covering 100 fields, was nearly completed and the section nearly ready for shipment to the subscribers.

INSTRUMENTATION

Spectrograph for Sixty-Inch Telescope

During the report year a new grating spectrograph has been put into service at the Cassegrain focus of the 60-inch telescope. The collimator is of an all-mirror Cassegrain type and has an aperture of 4 inches. The gratings are mounted in a turret which permits rapid interchange between gratings and which has provision for the simultaneous mounting of three gratings. Two gratings are now available; one, ruled with 600 lines per mm, is blazed at 3500A in the second order; the other, with 400 lines per mm, is blazed at 4200A in the third order or at 6300A in the second order.

Three cameras, of focal length 4 inches, 8 inches, and 16 inches, are provided. These yield dispersions of 80, 40, and 20 A/mm in the blue and ultraviolet. All cameras are of the on-axis schmidt type with field flatteners and twice-through corrector plates. The corrector plate of the 4-inch camera is of fused quartz, permitting observations to be made down to the limit of transparency of the atmosphere. Provision is made for offset guiding, for direct viewing of the field with a wide-field eyepiece, and for direct photography of a field while the spectrograph is in position. Preliminary tests indicate that it will be feasible to reach a limiting magnitude of about 13 at 80 A/mm with an all-night exposure.

Photoelectric Photometer for the Red and Infrared

The photoelectric photometry of very faint objects has in general been limited to wavelengths shorter than 6000A. This is because photoelectric receivers sensitive to the longer wavelength range tend to have both lower sensitivity and greater background noise than those sensitive to the shorter wavelength range.

Recently the Farnsworth Electronics Company supplied a red-sensitive photomultiplier having an extremely small photocathode. This was precisely what was needed for attempting to reach very faint objects in the red and infrared. A new vacuum-tight refrigeration chamber was designed by Baum to contain the new Farnsworth tube, and a special optical system using an oil-immersion microscope substage condenser was arranged to focus light on its photocathode. The chamber is filled with dry nitrogen, and certain parts are kept slightly warmer than others to avoid moisture effects. Some new electronic units were constructed to adapt the photometer to the photon-counting equipment now at Palomar.

This new red system was first used at the Hale telescope on May 19, 1955, and it successfully reached about the same level of operation thus far attained with the blue-sensitive system, namely, about one photon count per second.

Stellar Template Magnetometer

A new instrument, which may be termed a stellar template magnetometer, is under development by H. W. Babcock for the purpose of increasing the efficiency of observations of stellar magnetic fields. It will also be capable of measuring radial velocities and may be adaptable to certain more specialized investigations.

The new method depends on the use of a template of the spectrum of the star to be investigated, that is, an opaque strip with slits corresponding to the absorption lines in the spectrum. In most cases, the template will be simply an original spectrogram of a star of the appropriate type, photographed once for all. The template is placed in a special holder in the coudé spectrograph, and light of the star to be investigated is admitted to the entrance slit. Portions of the optical spectrum formed by the grating are transmitted by the numerous slits or line images of the template; this transmitted light is collected and admitted to a photomultiplier tube. For optimum signal-to-noise ratio, an a.c. method, involving small-amplitude oscillation of the optical spectrum while the template is slowly and accurately traversed along the spectrum under remote control, is used to locate the position of coincidence, which yields the Doppler displacement and radial velocity of the star. A measurement of the star's magnetic field is then made, with the template at the position of coincidence, by placing in front of the spectrograph an oscillating electro-optic analyzer for the elliptical polarization in the line profiles that results from the Zeeman effect. The photoelectric a.c. signal that results is proportional to the mean amplitude of Zeeman oscillation of all the spectrum lines transmitted by the template; this signal is nullified by adjusting the amplitude of an artificial anti-phase oscillation of the whole optical spectrum. The amplitude of this artificial oscillation (produced by a plane-parallel plate) is then a measure of the magnetic-field intensity of the star, and is independent of stellar magnitude and seeing.

Though this method of pursuing photoelectric spectrography can be expected only to supplement the photographic method, it appears to offer a number of attractive features: (1) It permits the realization of the far greater ($\times$ 1000) quantum efficiency of the phototube as compared with the photographic emulsion, even in what has been referred to as "the one-dimensional domain of the spectroscopist." (The application of the prospective astronomical im-

age tubes to precision spectroscopy at high dispersion appears remote.) (2) The photoelectric template method sums in one indicator reading the effect of numerous spectrum lines, and records this result in a time usually far less than that consumed at the telescope in photographing the spectrum. (3) The method eliminates the laborious and time-consuming task of measuring individually the Zeeman displacements of numerous lines on spectrograms. (4) The expected precision and limiting magnitude are estimated to compare quite favorably with those of the older photographic procedures.

In view of these facts, a photoelectric template installation for the coudé spectrograph of the Hale reflector has been designed by Babcock in collaboration with Rule and J. S. Fassero. The various units have been completed in the shop and are now being installed.

Solar Magnetograph for 150-foot Tower

A second solar magnetograph, designed by H. W. Babcock in collaboration with Nichols, has been under construction for the past two years and is now being installed in the 150-foot solar telescope on Mount Wilson. This will supplement the original installation in the Hale Solar Laboratory in Pasadena, which has been in use since 1952. It will have the advantage of greatly superior atmospheric conditions as well as certain technical refinements, and will be adaptable to various specialized research problems in addition to its primary purpose of continuing the daily sequence of solar magnetograms.

The magnetograph consists of two major elements: (*a*) a powerful spectrograph fitted with an a.c. analyzer and a photoelectric detector for measurement of extremely small Zeeman effects resulting from weak solar magnetic fields, and (*b*) a scanning system by which the image of the sun is swept slowly over the slit of the spectrograph in a raster (predetermined pattern), while a conformal mapping device records the magnetic field intensity and polarity in the form of a magnetic map of the solar disk.

The 75-foot spectrograph has been equipped with a new plane grating of high quality, yielding, in the fifth order, a dispersion of 0.09 A/mm and a resolving power of about 600,000. The analyzer for Zeeman polarization consists of an electro-optic retardation plate excited at 60 cycles per second and followed by a plane polarizer. Successful performance of the instrument depends critically on the use of two exit slits, on opposite sides of a chosen sensitive spectrum line, these slits admitting light to separate photomultipliers that are connected to a difference amplifier and hence to a synchronous filter. The new magnetograph has been designed to accept light from two spectrum lines instead of one. Further, because the limit of detectability is set by statistical fluctuations in the photo-current, it is expected that a significant improvement can be attained by increasing the available light, and it is planned to accomplish this with the aid of a Bowen image slicer.

The scanning system utilizes a primary motor and transmission driving two Selsyn transmitters and five Selsyn repeaters in a coupled arrangement with the necessary relays for switching, reversing, and spacing. This self-synchronous system is capable of carrying out a complete scanning of the sun, with recording by means of a cathode-ray tube and a camera making a time exposure. The entire operation is automatic.

Exposure Meter

Largely because of variations in seeing, the proper estimation of exposure times for the large coudé spectrographs is difficult. For this reason, an integrating photoelectric exposure meter has been installed in the large spectrograph of the Hale telescope. A small fraction of the light passing the slit (otherwise intercepted by an on-axis plateholder and wasted) is admitted to a photomultiplier tube with associated pulse amplifying, counting, and scaling circuits.

Even without refrigeration and without compensation for dark current, the meter has proved useful on stars fainter than the tenth magnitude. Later, if compensation is added, the range will be extended.

Gratings

Babcock and Swanson have improved the smaller ruling machine by replacing the cast-iron bearings of the main screw with new ones of Graphitar, and have installed a new diamond end-thrust bearing. New and more precise intermediate spacing gears have been mounted. Considerable attention has been given to the preparation of special ruling diamonds. A principal effort consisted in attempting to rule the best possible grating of high resolving power and large size (6×10 inches). Several attempts were made, but perfection has not yet been achieved, mainly because of wear of the ruling diamond. The general level of performance of the machine remains high.

GUEST INVESTIGATORS

In conformity with their usual policy, the Observatories have invited a substantial number of guest investigators from other institutions to make use of such facilities as were not required by the programs of the regular staff of the Observatories. These guest investigators have made observations for the following programs.

The photography in the ultraviolet and infrared of certain sections of the lunar surface has been continued at the Cassegrain focus of the 60-inch reflector by Dr. Dinsmore Alter, of the Griffith Observatory. Plates of the necessary quality can be obtained only on nights of unusual seeing. Of approximately two dozen nights when work was scheduled, only two showed the necessary steadiness of the atmosphere. Recently a new plateholder with filter holder and shutter has been completed by the Griffith Observatory. This will permit the taking of lunar photographs, when unusually fine seeing occurs, without the necessity of removing the spectrograph.

In October 1955, Dr. James Cuffey, of the Astronomy Department of Indiana University, used the 100-inch reflector on six nights to photograph the globular clusters NGC 2158, 6838, and 7492 in yellow and in blue light. Seventy-five plates were obtained, which are being measured in order to determine color-magnitude relations. Magnitude sequences in the clusters are being derived from photoelectric and photographic work with the 36-inch reflector at the Goethe Link Observatory of Indiana University.

NGC 7492 is interesting because of its well-resolved structure and its high southerly galactic latitude. NGC 2158 and 6838 are rich objects once classified as galactic clusters. Earlier photometry by Dr. Cuffey showed their color-magnitude relations to be similar to those of globular clusters. This fact, and their position far from the galactic nucleus, render them unusually interesting objects.

An extensive investigation of the eclipsing binary λ Tauri has been carried out by Dr. E. G. Ebbighausen, of the University of Oregon, in collaboration with Dr. Otto Struve, of the University of California.

The period of the eclipsing pair is nearly 4 days; about 1910 Schlesinger discovered a third body with a period of 34.6 days. In 1923 McLaughlin reinvestigated this object but arrived at a period of 30.0 days. Dr. Ebbighausen's investigation is an attempt to resolve this difference in period and also to consider possible perturbations in the elements of this system, since the ratio of the long to the short period is so small.

In 1952 and 1953 Dr. Struve secured 160 spectra of λ Tauri. In November 1954 and February 1955 Dr. Ebbighausen secured 190 additional spectra, making a total of 350 spectra obtained with the 60-inch at Mount Wilson using the 18-inch camera.

The analysis of the Mount Wilson data is nearly finished, and it appears that the longer period is very close to the 30.0 days obtained earlier by McLaughlin. So far no obvious changes in the elements have appeared from the analysis of the data.

Between December 1954 and May 1955 Dr. Erik Holmberg, of Lund University, Sweden, obtained many additional plates for his program on the photographic photometry of galaxies. With the aid of the 60-inch and 100-inch telescopes about 800 exposures have been made of nebular fields and suitable comparison areas. The plates, which are being measured at Lund, will yield total photographic magnitudes and color indices for about 150 objects. The material mainly includes near-by galaxies of large angular dimensions, for which the photographic method seems to give more reliable results than photoelectric measures. The work is a continuation of the previous photometric program, comprising 120 near-by galaxies, which was based on plate materials obtained at Mount Wilson Observatory in 1947 and 1951.

An investigation of the color-magnitude diagram for individual stars in M 33 was begun by Dr. H. L. Johnson, of the Lowell Observatory, in collaboration with Sandage. Photoelectric observations in three colors were made on twelve nights in the fall of 1954. For the faint stars observations were made with the integrator-type d.c. amplifier developed at the Lowell Observatory. The photoelectric observations have been reduced and are ready for use in the calibration of the photographic work. The faintest star that was observed has V=20.8, B=21.7.

Dr. Philip C. Keenan, of the Perkins Observatory, carried out a spectroscopic study of luminosity and composition of S-type and related stars during the fall of 1954 and winter of 1955. Spectrograms were taken, with the coudé spectrograph of the 100-inch telescope, of 6 S-type stars for which reliable radial velocities were not previously available because of their faintness. All together 40 usable spectrograms of S-type stars were obtained, and it is expected that intensities of lines and bands will be determined on most of these.

The spectrum of the Se long-period variable R Geminorum was extended into the near infrared as far as 8700A with a dispersion of 20 A/mm. Since spectrograms of standard M-type stars were taken over the same range of wavelengths, it will be possible to compare line intensities in types S and M from 5000A to 8700A. The table of wavelengths and estimated intensities is now being completed. The 1955 maximum of R Geminorum came in March, several weeks earlier than predicted, and was unusually bright. The spectrograms taken when m_v was brighter than 6.8 show that the level of excitation in the atmosphere was considerably greater than at the same phases in 1952 and 1953, when observations were also made at Mount Wilson.

Most of the features in the spectrum of R Geminorum have been identified, and the strongest atomic lines in the red are found to be resonance lines of the heavy metals: *Zr, La, Y,* and *Gd.* There is, however, one strong line at 7033.7A which has not been identified with any line known in laboratory spectra, although its stellar behavior suggests that it is a resonance line of a neutral atom.

Measurements of the diameters of Enceladus, Tethys, Dione, Rhea, Titan, and Iapetus, all satellites of Saturn, and of Triton, a satellite of Neptune, were made on the evening of July 4, 1954 by Dr. Gerard P. Kuiper, of the Yerkes Observatory. The measurements were made with a disk meter attached to the 200-inch telescope. At the same time the rings of Saturn were examined for "divisions," and Neptune was studied for limb darkening and the presence of spots. During the winter of 1955 Dr. Kuiper spent eight nights in observing the moon with the 60-inch telescope. A binocular attachment of wide field and a power of 800× was used visually. Much new information was assembled, but one object discovered visually

deserves special mention: an object smooth and white as a pebble, about 5 km long and 2–3 km in diameter, lying just west of the crater Tycho. An extensive study was also made of the over 500 photographs of the moon in the Observatory files.

Dr. R. B. Leighton, of the Norman Bridge Laboratory of Physics, used the 60-inch telescope on five nights for the photography of Mars on 16-mm Kodachrome film. The automatic guider and the prism compensator for atmospheric dispersion developed by Dr. Leighton for this program worked satisfactorily. The photographs of Mars show many features in the region of Margaritifer Sinus, and also show clearly some effects of atmospheric haze in the northern polar region and in the twilight zone.

The quantitative use of color film for planetary studies appears to be both feasible and, in some respects, desirable. A standardized light source with color filters has been constructed, and tested with a standard color sequence on each roll of film. This reduces the uncertainty in the color calibration of the film that is introduced by the processing procedure.

During July and August 1954 Drs. William Liller and L. H. Aller, of the University of Michigan, observed photoelectrically 104 planetary and emission nebulae. They accurately determined the brightness of these objects in the light of the oxygen [*O* III] line at λ5007, which was isolated with a 40A half-width interference filter. By using a conventional glass filter which transmitted light from λ5100 to λ6000A, Drs. Liller and Aller obtained an upper limit of brightness for each exciting star. For a few bright planetary nebulae accurate central star magnitudes and colors were obtained by driving a narrow slit across the nebula and measuring the height of the central hump in the resulting intensity trace. The observations of the exciting stars were reduced to the Johnson and Morgan magnitude and color system.

Nebulae for which it is possible to derive accurate distances received particular attention. Included were several emission objects in M 33, the planetary nebulae in the globular cluster M 15, and a few planetaries whose central stars are members of binary systems.

The project for investigation of the solar spectrum with the Snow telescope has been continued for the sixth year by the McMath-Hulbert Observatory. Mr. Walter E. Mitchell, Jr., observed throughout the year; Dr. O. C. Mohler was in residence on Mount Wilson between August 15 and September 15, 1954, and made a large number of observations of the K line of calcium.

The program of observations for this report year has been as follows: Observations to detect either seasonal or short-period variations in CO and CO_2 have been continued. The systematic observation of the infrared helium line at 10830A at the limb of the sun and in plage regions has been continued. Drift curves for the derivation of solar-limb darkening in the 4-micron region were made on a number of days. A 1 P 21 photomultiplier, sensitive throughout the visual and ultraviolet part of the spectrum, has been used for recording the central structure of the K line of calcium. This equipment has also been used for the study of the profile of the $H\alpha$ line in an attempt to detect the presence of heavy hydrogen in the sun. A few tracings have been made of the lines supposed to be *Tc* II in the ultraviolet part of the solar spectrum. Mr. Mitchell has made many observations of a selective series of lines that show a large variation from the center to the limb of the sun. The new mapping of the spectrum between 8000 and 25000A with a high-resolution grating has been completed. The spectrograph has been maintained at the high level of performance mentioned in the last report, and practically the full resolving power of the grating can be obtained.

Observations have been made on 207 days, and a total of 1700 tracings was accumulated during the year. The table of wave-length measurements to accompany

the infrared atlas is in the hands of the printer.

In December 1954 Dr. D. H. McNamara, of the University of California, obtained spectra of stars in the galactic clusters M 36, NGC 2362, and the h and χ clusters in Perseus. These spectra have been used to calibrate the equivalent widths of the hydrogen lines with absolute magnitudes of B stars. The calibration will subsequently be used to improve the absolute magnitudes of the β Canis Majoris stars.

Dr. Daniel M. Popper, of the University of California at Los Angeles, has completed a five-year search for cyclic variations of H and K emission in the spectra of dwarf stars. The results are essentially negative except for the single spectroscopic flare of HD 234677, reported last year. The search for variations in stars with hydrogen emission, given impetus by the discovery last year of variation in the spectrum of HD 224085, has also been discontinued, since it turns out that this star is a spectroscopic binary. The conclusion from this investigation is that, whatever the process responsible for producing H and K emission lines in dwarf stars, it is a relatively stable one in periods of the order of a solar cycle.

Provisional masses for components of eclipsing binaries lying above the main sequence have been determined by Dr. Popper as shown in table 4. The last two are improved determinations for well-known systems, largely from coudé material. A combination of new spectroscopic and photoelectric (Mount Hamilton) material has removed outstanding discrepancies in the interpretations of these two systems. The 98-day eclipsing binary UU Cancri has a spectral type of K4 III for the brighter component, with strengthening of the hydrogen lines except at primary minimum. The radial-velocity range is about 65 km/sec. Because of the difficulty of finding features of the hotter star in the spectrum, there is a question whether this system can add to the very meager collection of masses of stars above the main sequence.

Dr. Jorge Sahade, of the Cordoba Observatory, has carried out observations of β Lyrae and π Scorpii in collaboration with Dr. Struve. Spectrograms have been taken with the 100-inch telescope for the purpose of redetermining the orbital elements and studying the short-period variations. Observations of the stars 23 Sextantis, π Scorpii, and HD 199908 have also been made by Dr. Sahade with the 60-inch telescope. The star 23 Sextantis had been announced as a short-period variable, but spectrographic observations have failed to show any definite variation in velocity. Preliminary measurements of HD 199908 show a variation in velocity with a range of the order of 10 to 15 km/sec and a period in agreement with the photometric value.

TABLE 4

Star	Spectrum	Mass
TW Cancri	G8 III	2.7 solar masses
RZ Cancri	K2 III	2.6
RZ Cancri	K4 III	0.4
Z Herculis	G8 IV	1.2
Z Vulpeculae	A3 III	2.3

A study of line broadening in the O- and early B-type stars has been carried out by Dr. Arne Slettebak, of Perkins Observatory. The aim of this program is to determine the relative importance of line-broadening agents such as axial rotation and large-scale turbulence in the atmospheres of these stars. This is being done in two ways: (1) Accurate line profiles of a number of the bright O- and early B-type stars are being derived from high-dispersion spectrograms, with the aim of comparing these with computed profiles derived under the assumption of various types of line broadening. Coudé spectrograms of 38 stars have been obtained by Dr. Slettebak with the 100-inch telescope for this purpose, and similar spectrograms of 8 additional stars obtained by Dr. J. B. Oke are also being analyzed. (2) A study of line broadening as a function of position on the

Hertzsprung-Russell diagram for the O- and early B-type stars is being carried out, with the help of visual estimates of line broadening made from spectrograms of nearly 200 stars in the Mount Wilson and Palomar files. The data come primarily from the large collection of O- and B-type spectrograms taken by Münch in his work on the interstellar lines.

Dr. Lyman Spitzer, of Princeton University Observatory, obtained a number of high-dispersion spectrographic plates of the shell stars HD 33232, 1 Delphini, and HD 195407. This observational material will be used in an analysis of the physical conditions in these extended stellar atmospheres. In addition, spectrographic plates were obtained of one G0 subdwarf and two dwarfs of neighboring spectral types, in order to determine the effect of absorption lines on the color indices of these stars. Analysis of this material by Schwarzschild, Searle, and Howard indicates that the relative absence of absorption lines in the blue region of the subdwarf spectrum decreases the color index of a subdwarf by about 0.8 mag., relative to a normal dwarf of the same effective temperature. Thus this effect accounts for about half the distance of the subdwarfs below the main sequence on the H-R diagram.

The program for the observation of the far infrared radiation of Venus and Mars, started with the 100-inch telescope in 1952 and continued with the 200-inch in 1953, was completed during the current year by Professor John Strong and Dr. William M. Sinton, of the Johns Hopkins University. The 7–14-micron band of radiations from Mars, which our atmosphere transmits, gave adequate signal when an area of the planet of 2″ diameter was used. Many scans, using such an area, were made across the planet's surface. These revealed relative emission, and consequently surface temperatures. A provisional value of the thermal diffusivity of the planet's surface will come from these observations. However, the determination of relative Martian surface altitudes, which was one objective of the program, requires more observations than were obtained.

Comparable spectra of Mars, Venus, and the moon were obtained from 7 to 14 microns with a resolution of 8 cm^{-1}. No absorptions appeared in planetary spectra which were not present in the moon's spectrum. Subtle differences in these three spectra, however, will no doubt reveal new information about the planetary atmospheres, when their reduction is finished.

Dr. Otto Struve, of the University of California, continued his program for the study of the β Canis Majoris sequence of variable stars. The highlights of this work were as follows: The velocity curve of BW Vulpeculae, σ Scorpii, and DD Lacertae was discovered to be discontinuous. The nature of the discontinuity resembles that previously found in RR Lyrae, but differs from it because of the presence of a short, intermediate branch of the velocity curve on what was previously regarded as its descending branch. Additional observations of ν Eridani confirm the beat phenomenon previously established, and show that a third period of 0.06 day, with K = 5 km/sec, is present. An attempt was made to extend the sequence to stars of lower luminosity and shorter period than γ Pegasi (P = 3½ hours), but the B3 variable 23 Sextantis, whose photoelectric period is 2½ hours, fails to show a change in radial velocity. Several pairs of spectrograms of Maia = 20 c Tauri show changes in radial velocity within intervals of one hour. This star may be a member of another sequence of pulsating variables. More observations are required.

Special attention was given to the problem of stellar evolution, as reflected in the abundances of the elements in the atmospheres of stars. For this purpose Maia is being investigated in detail. It is an overluminous B8 member of the Pleiades. Also in connection with stellar evolution, the spectrum of β Lyrae was investigated, using Process plates and the 32-inch camera of the 100-inch coudé spectrograph. The results indicate substantial changes since

this star was investigated at the Yerkes Observatory, twenty years ago.

Epsilon Aurigae has been observed with high dispersion on several occasions. The presence of sharp absorption lines from an atmospheric eclipse (especially *Sc* II 4247) was definitely established in May. The discussion of the vast amount of old and new Mount Wilson material on this star is in progress. The B0 spectroscopic binary π Scorpii was investigated in order to study the character of its double absorption lines. The spectra of a few pairs of visual double stars were obtained for the study of atomic abundances. The entire material on these binaries will also be used for a study of their radial velocities.

Dr. A. D. Code and Dr. A. E. Whitford, of the Washburn Observatory, University of Wisconsin, continued their program of measuring the relative energy distributions of bright stars with a photoelectric scanning spectrograph during the summer and fall of 1954. A wave-length range from 3400A to 10,000A is covered with a resolving power of approximately 15A. Observations to date include some forty stars, selected as representative of the principal stellar types. The scanning spectrograph was used also to measure emission-line intensities in the Orion nebula and the planetary NGC 7027.

A considerable fraction of the observing time was devoted to absolute calibration observations in order to put the relative measurements on an absolute energy basis. The basic program consisted in observing alternately a bright star and a standard lamp through a 3-inch quartz objective. Interference filters were employed for isolating the desired spectral regions. The standard lamp was measured through the same optical system with a thermocouple. The lamp is at present undergoing laboratory calibrations, and until these are completed the full weight of these observations cannot be evaluated. The thermocouple measurements, however, yield results in substantial agreement with the energy distribution determined by Williams, and by Williams and Hall, for Vega.

As a supplementary calibration, the stellar energy distribution was compared with that of the sun, by use of a neutral sun reducer based on a series of negative quartz lenses. This method is dependent, however, on the accuracy of the accepted solar-energy distribution curve.

Dr. Whitford's investigation of the energy distribution of radiation from distant galaxies, mentioned in the 1952–1953 report, was resumed in the spring of 1955. Twenty elliptical galaxies in clusters were measured photoelectrically in six color bands centered on wavelengths ranging from 3400A to 8700A. The brightest systems in the Virgo and Coma clusters, used as near-by samples, were observed with the 60-inch telescope; the 200-inch telescope was used for the more distant clusters. One of the brightest members of the very remote Cluster 1448+2617, a system of visual magnitude 20.8, was the faintest object measured. A few faint spirals with known radial velocity were also observed.

Analysis of the results is expected to provide a test of the hypothesis that the color-excess effect, first observed by Stebbins and Whitford in 1948, is the result of evolutionary changes in a stellar population, and perhaps to give an indication of the types of stars that might play the major role in such changes.

STAFF AND ORGANIZATION

Dr. Edison Pettit retired on June 30, 1955. Soon after joining the staff of the Mount Wilson Observatory on September 1, 1920, Pettit developed in collaboration with Nicholson a very sensitive vacuum thermocouple. With this instrument Pettit and Nicholson made an extended series of measurements of the infrared radiations

from a number of stars and planets and the moon. Their results provided a wealth of information on the temperatures of these bodies, and, in the case of the moon, on the thermal properties of its surface rocks. Later Pettit made a large number of observations of solar phenomena. These included studies of the ultraviolet portion of the sun's radiation and its fluctuation with time, and a detailed study of the prominences and their motions. Since World War II he has measured with a photomultiplier tube the magnitude of 561 galaxies whose velocities had been determined by Humason. The measurements by these two observers provide the basic data for a critical analysis of the distance-velocity relations of galaxies.

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Karl G. Henize
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Alexander Pogo

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Edgar C. Nichols, Chief Designer, and Superintendent, Instrument Shop
Bruce Rule, Project Engineer
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Raymond L. White, Powerhouse Operator

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JOINT COMMITTEE ON IMAGE TUBES FOR TELESCOPES

Co-operative Project of Mount Wilson and Palomar Observatories, Department of Terrestrial Magnetism, National Bureau of Standards, United States Naval Observatory, and California Institute of Technology

JOHN S. HALL, *United States Naval Observatory*
W. A. BAUM, *Mount Wilson and Palomar Observatories*

The investigation of Image Orthicons and Vidicons, discussed in the report last year (see Year Book No. 53, 1953–1954, pp. 39–41), was concluded in December 1954. This work was carried out at the National Bureau of Standards by Dr. E. S. Dayhoff under the direction of Dr. L. L. Marton. Except for certain limited applications involving high surface brightness, such as the observation of planets or the solar spectrum, it was concluded that the Image Orthicon in its present commercial form would require several fundamental modifications or improvements to meet the low-level requirements of primary interest to this committee. Two types of improvement would be essential. One of these is concerned with the electronic integration and storage of an image for a sufficiently long time without loss of definition; the second concerns the present difficulty of transferring the electronically stored image to a permanently recorded picture without serious loss of useful information. Work on electronic-storage tubes such as the Image Orthicon is being carried out at several laboratories. Although these will be watched with considerable interest by the committee, it was decided that a new project in this field was not justified and that the efforts of the committee should be turned to a channel of more immediate promise.

Although the selenium Vidicon was found to have more favorable storage properties than the Image Orthicon, the problem of transferring the electronically stored image to a permanent record without loss of information was even more difficult with the Vidicon than with the other instrument. This committee is indebted to Mr. F. S. Veith and his associates at the Lancaster Division of RCA for the loan of a selected Image Orthicon and two selected Vidicons which were used in making these tests.

There are two general methods by which the advantage of photocathodes over photographic emulsions can be utilized, the advantage, of course, being that which results from a 100-fold gain in quantum efficiency. One method, which is represented by the Image Orthicon and Vidicon, uses the accumulation and storage of images in the form of electric charges from which a background, such as that due to the night sky glow, can be subtracted electronically before the enhanced picture is displayed or recorded. The other method, which is represented by the various types of "image converter," utilizes a recording medium of high storage capacity, such as a very fine-grained photographic emulsion, to register all the photoelectrons including those from the background. In principle, the two methods offer identical opportunities for an improvement over unaided photography, but in practice some of the image converter schemes appear to have more immediate promise for low light-level applications entailing long exposures.

During the first half of 1955 the committee launched an effort to develop a particularly promising type of image converter for mass production. This device, called the "thin-film converter," has a very thin film stretched across the end where the phosphorescent screen would otherwise

be located. The photoelectron beam can pass right through this film, but gas molecules cannot; consequently, the thin film permits the electronic image to be formed outside the tube while the high-quality vacuum inside the tube is preserved. When a photographic plate is placed behind the thin film, the impinging electrons create a latent image just as in Lallemand's system (described in the previous report). Laboratory experiments of a similar nature have also been carried out by Hiltner and collaborators.

The Farnsworth Electronics Company and the Radio Corporation of America are both co-operating with the committee in the experimental production and testing of these new tubes. The present model is about 5 inches long and comes complete with photocathode, electron optics, and thin film. Since the thin film would be ruptured by atmospheric pressure, the tube is supplied during manufacture with an evacuated glass cap covering the rear end. A spare stock of tubes can thus be kept on the shelf until needed.

When a tube is put into operation, it is installed in a vacuum plate changer. This device provides a rough vacuum around the rear end of the tube so that the protective glass cap can be safely removed from behind the thin film; it also provides a means for getting photographic plates in and out of the system without breaking the vacuum. It is hoped that this technique will eventually enable astronomers to obtain plates with image tubes in a fashion as routine as that already achieved in electron microscopy.

The primary remaining problem concerns finding the best procedure for producing thin films having optimum characteristics. Many experimental films have been made by Dayhoff at the Bureau of Standards and by Stewart Sharpless at the Naval Observatory, and similar exploration is now being carried out by W. K. Ford at the University of Virginia. The present specifications require that the thin film be self-supporting across a circular aperture 10 mm in diameter, that it withstand a differential pressure of 10^{-5} atmosphere, that the gas leakage through it be negligible, that attenuation of the electrons be less than 10 kv, that the loss of resolution due to electron scattering in the film be minimized, and that the film be undamaged by the baking process required in commercial tube production.

As a second line of attack, an attempt is being made to develop a special type of thin-film converter capable of withstanding full atmospheric pressure, thereby avoiding the complications of the vacuum plate changer described above. In this case the aperture covered by the thin film can be only a narrow slot, but such a slot would be sufficient for many spectroscopic applications. A film of dural 700A thick was found to withstand atmospheric pressure when mounted across a slot 0.1 mm wide by 12 mm long. Although the scattering of 15-kv electrons by this film was two or three times the desirable maximum, these preliminary results have convinced the committee that there is a possibility of using a spectroscopic image converter at atmospheric pressure.

In addition to the thin-film converter, the committee is also interested in a special type of converter developed for the Bureau of Ships by Dr. G. A. Morton, of the RCA Laboratories at Princeton. This tube utilizes a cathode, two stages of intensification, and a phosphorescent screen which may be photographed with an ordinary camera. Tests on this tube are to be made at the Bureau of Standards under the supervision of Dr. L. L. Marton.

Measuring the residual magnetization of ancient rocks, Monument Valley, Arizona-Utah

The measurement of the earth's present magnetic field requires a vast number of observations over the continents and oceans; to obtain reliable information concerning the variations in such a magnetic map during the past several hundred million years, by measuring the magnetization of rocks, necessitates careful discrimination, with constant watchfulness to avoid biasing the final results. It is obviously not possible to measure rocks of all ages in all locations, but significant progress nevertheless is being made on this problem. Criteria developed during the past ten years have already demonstrated that the magnetization found in most rocks is not reliable; thus the remanent magnetic directions only of rocks selected for consistent patterns, with separate evidence for stability, can be considered indicators of the history of the earth's magnetic field. Measurements in Monument Valley of the earth's magnetic field in certain geological epochs agree with similar indications found in England for those same epochs. Observations are now needed from Africa, South America, and perhaps Australia.

DEPARTMENT OF TERRESTRIAL MAGNETISM

Washington, District of Columbia

MERLE A. TUVE, *Director*

The activities of this Department during recent years provide a vigorous demonstration of the fact that in many areas of modern science the trend toward narrow specialization has progressed so far that it has reversed itself. In order to answer some of the most interesting and obvious questions which arise as he probes deeper into the fundamentals of his own specialty, the investigator often finds now that he must widen his range of knowledge and interests in unexpected and unfamiliar directions. For many decades the traditional pattern has been for a small segment of a broad subject to form a research area of particular interest to only a limited group. These specialists would then proceed to develop their subject in relative isolation, and after a few years even the technical language they used would be fully intelligible only to the members of the group.

This pattern still holds, of course, in certain fields, but in many areas of natural science the specialists have carried their studies to the point where their really large and interesting questions overlap the detailed interests of investigators whose training and background experience lie in entirely different areas of science. Thus the physicist and the astronomer, after some hundreds of years of separate identity, are, during the past few decades, again often the same man. The chemist and the physicist now share large areas of knowledge and competence. It is less frequently the case for the geologist and the physicist to find themselves with the same detailed enthusiasms and pursuing the same questions, and perhaps still less usual for the biologist and the physicist to acquire whole segments of knowledge and competence from each other. The physicists who comprise the staff of this Department, however, have accepted the opportunity and responsibilities of freedom in research, and each staff member has undertaken to develop his personal competence accordingly. They have chosen to explore many questions not usually found on the research agenda of a physics laboratory, and the report below describes studies, often carried on jointly with visitors or associates in other disciplines, on problems in geophysics, astrophysics, and biophysics, along with studies on some of the more traditional topics of research in physics.

One of the most interesting and unexpected events during this report year was the discovery of intermittent, high-intensity radio emission from the planet Jupiter. The small group using the "Mills Cross" array of antennas, described last year, for their studies in radio astronomy found a variable 22-megacycle source of small dimensions in the constellation Taurus. At first this was thought to be local electrical interference of unusual intensity at a late hour in the evening, from an auto or other obscure source on the farm where the antennas are located. After a few weeks of this nuisance, however, it was noticed that the interference was progressively earlier each time it was observed, apparently following sidereal time. Careful studies then showed the source to follow the movement of Jupiter as it changed its position among the stars. This radio emission, which is observed about one day out of three during the fifteen-minute interval when Jupiter is in the antenna beam, is characterized by intense bursts, comparable to those from the strongest radio sources in the sky.

Other members of the staff group which have undertaken to explore the new field of radio astronomy have carried out a comprehensive series of measurements on the distribution of hydrogen clouds in sev-

eral sectors of our galaxy, measuring both above and below the plane of the Milky Way. Their observations strongly indicate that our solar system is near the inner edge of a local arm, and that this arm is not circular about the center of the galaxy, but is strongly inclined. The outer arms, clearly separated, appear to be more nearly circular, but more detailed observations may revise some of the earlier descriptions of these gas clouds, which are under observation at only three or four places in the world.

Observations using specialized radio equipment and directed toward specific questions were also carried out this year on the intensity distribution of the "quiet" sun emission and on the low-frequency radio emission from several of the most intense sources in the sky, seeking to differentiate between thermal and other possible mechanisms for the production of these radiations.

After seven years of summer field studies using waves from explosions to study the structure of the crust of the earth, an expedition to the Rocky Mountains was undertaken in the summer of 1954, despite our confident expectation that the measurements would disagree among the different localities and in general would show the mountainous region to be also a region of confused crustal structures. Previous efforts to measure the structures in California and near Puget Sound had given uncertain results of this kind, but the principle was clear that knowledge of the earth can rarely be increased by staying at home and lamenting the confused state of its structures. The first three days of observations, on waves from copper-mine blasts which occur daily there, gave the unequivocal result that the sharp boundary between crust and mantle lies at the same depth under the Colorado Plateau in Arizona and New Mexico as under the coastal plain in Maryland and Virginia. Textbook views would place this boundary much deeper under the mountains, which were assumed to float more or less as icebergs float, with a deeply immersed "root." The same surprising result was found, later in the summer, under the mountains of Utah.

One "big" question in geophysics which has been the subject of many research attempts since the early 1930's in this Department has concerned the possibility that the outer shell of the earth may have shifted radically during geologic time with respect to the constant north-south axis of the earth's rotation or spin. Compensating shifts of the heavy core could easily have occurred, since the earth is not a solid ball, but a "two-piece gyroscope" with inner and outer spinning parts coupled together by fluid and electromagnetic forces. The westward drift of the secular magnetic variations, known since Halley's comments in 1692, is one evidence of these internal motions. Beginning about 1937, studies here of the magnetization of ancient rocks gave some hope that evidence for major shifts of the geographic poles (actually, of course, shifts of the earth's geography with respect to the fixed axis of spin) might be found by careful studies of the faint magnetic patterns embedded in the rocks. Since World War II our many observations of Tertiary, Mesozoic, and Paleozoic rocks of the United States have failed to give reliable indications of a shift of the poles, although evidence for such a shift was found in 1948 (see Year Book No. 48, 1948–1949, p. 8). In 1954 Clegg and his colleagues found a consistent pattern of magnetization, very different from the earth's present magnetic field, in late Paleozoic and Triassic rocks of England; these observations would place the average magnetic pole (hence geographic pole) roughly in South Korea during that epoch. Rocks of similar age are exposed in this country over a wide region of Arizona and New Mexico, and an expedition from our Department this year showed that the rocks of our Southwest give about the same location for the magnetic pole in Permian time that is indicated by the rocks of Great Britain. The Triassic rocks sam-

pled in Arizona gave inconsistent results, but if future observations in South Africa, Brazil, and Australia give similar indications for Permian time, a new feature, the shifting of the equator and the poles, will henceforth enter our reckoning of the earth's history.

After a series of seminars on "Milestones in the Pre-Cambrian," a program was initiated here several years ago to utilize the new resources of nuclear physics and chemistry in a systematic effort to provide a dating system for ancient rocks. The isotope relations of the various radioactive families, uranium and thorium to lead, rubidium to strontium, and potassium to argon and calcium, will serve to measure the date of the last clean-cut chemical separation of these dissimilar elements in rocks, as in the fractionation which accompanies the formation of crystals, provided later subtle changes, as by leaching or diffusion or the alteration of crystal structures, have not removed part of the parent or daughter elements of these radioactive families. During this report year many of the precautions and tests necessary for reliable results were clarified and reported, and discrepancies in certain physical constants of radioactive nuclei have been high-lighted. The initial objective of achieving a means for the dating of igneous intrusives seems nearly at hand. The geological use of this powerfully analytical probe will be of great interest.

The familiar picture of "magnetic storms," which disrupt telegraph and radio circuits and are accompanied by displays of "northern lights," as being due to streams of particles from the sun is still under scrutiny. The possibility remains that many features of these disturbances, although "triggered" by the sun, perhaps by ultraviolet light, may arise from terrestrial disturbances such as winds in the very high atmosphere, and perhaps even electrical discharges there of the same character as the phenomena in a Geissler tube or a neon sign. Studies of these puzzling alternatives are continuing.

During the past two years the activities of the small group of physicists here who are studying processes which occur in living matter have changed in emphasis from examination of the incorporation of inorganic atoms to form amino acids and similar small sub-units to larger questions concerning the organization of these units into the highly complex and specific proteins and nucleic acids which are recognized as the essential "life components" of living cells. These structures, as distinct, for example, from the "fuel components," convey the information and initiative necessary for genetics, and for the organization of the new growing cell as an entity. The fascinating questions as to how such information can reside in the "space structure" of the nucleic acids which function as chromosomal material or as virus particles provide opportunity for the physicist to apply his patterns of thinking and experiment in fresh directions. During the course of this report year the studies of this group have been focused largely on the "sites" which must be occupied or filled, on some previously organized template or space pattern (inherited), before synthesis of new protein or nucleic acid can occur. The fascinating ramifications of these ideas and experiments are just beginning to be evident.

EXPERIMENTAL GEOPHYSICS

RADIO ASTRONOMY

B. F. Burke, J. W. Firor, K. L. Franklin, and H. W. Wells

The 22 mc/sec "Mills Cross" antenna, described in the previous report, was first operated July 20, 1954. The system behaved much as expected, with a beam width (at half power) of approximately 1°. The first observations demonstrated that side-lobe suppression is necessary, for otherwise, spurious responses from strong sources outside the main beam of the an-

tenna make interpretation of the records very difficult. For linear arrays, side-lobe suppression is usually accomplished by tapering the excitation of the elements of the array, the result being relatively less contribution from elements near the ends of the array. The Dolph-Tchebyscheff distribution provides an optimum tapering in the sense that for a given side-lobe level the beam width is as small as possible. The tapering was accomplished by inserting attenuators of proper value into the feeder system, the attenuation being calculated to give 40 decibels side-lobe suppression in each array, or an effective over-all side-lobe suppression of 20 db (since this type of antenna multiplies amplitude, rather than power, gains). The tapering increased the beam widths by about 50 per cent, the over-all loss in antenna gain being about 3 db. The first observations with the tapered arrays indicated that the suppression was effective, although for certain phasings of the array unwanted responses sometimes appeared. Nevertheless, it was possible to initiate survey work by the middle of January, when auxiliary electronic equipment, including a total power receiver, had been completed.

The survey work planned for the instrument has progressed at a much slower rate than was expected. During the winter months, interference from ionospheric signals during the day made observation impossible, although the night hours were, almost without exception, free from man-made interference. Scintillation was a serious problem, and as much as a week might pass before a single good record was obtained of a given source. In addition, on successive nights the apparent intensity of a given source changed by small amounts, even when little scintillation appeared to be present, an effect which may be in part instrumental, but is also in part caused by variable ionospheric absorption. For these reasons, multiple-strip recording is planned to begin shortly, to speed up the process of data taking.

Instrumental reliability has left something to be desired, the total power receiver giving useful records no more than half the time. Mechanical difficulties with the capacity switch used in this receiver have been corrected, but operation with the modified switch has not yet continued for a long enough period to demonstrate its reliability. In contrast, the phase-switching receiver, which is now of a design similar to that used in the solar interferometers, has been extremely reliable, and over a five-month period only one instance of electrical failure occurred. A number of the principal sources have been observed and preliminary intensities obtained, including Cassiopeia A, Cygnus A, M 1, NGC 1275, IC 443, and NGC 4486. In all cases, the intensities of these sources are greater at 22.2 mc/sec than at higher frequencies, agreeing roughly with a linear extrapolation of the intensities at higher frequencies (linear, in this case, referring to a log-log plot of intensity vs. frequency). A notable exception was M 1, the Crab nebula, which appears to have a spectrum that is approximately constant in the 100 mc/sec region, but that is considerably more intense (5.2×10^{-23} wm^{-2} sec) at 22 mc/sec.

One of the most interesting results obtained with the Mills Cross is the detection of Jupiter as a source of radio emission. During modification and development of equipment, the pencil beam of the antenna was directed for the first quarter of 1955 to a declination band containing the Crab nebula. In nine out of thirty-one instances, the records showed an event occurring about two hours after the transit of the Crab nebula. These events were characterized by the appearance of distinct bursts, occasionally of such intensity as to be off the scale of the recorder (fig. 1). The effect was not unlike that produced by terrestrial interference, but this phenomenon never lasted for more time than was necessary for a celestial object to pass through the pencil beam of the antenna. Further-

more, the effect was observed at night, when terrestrial interference was extremely rare.

By plotting the apparent position on the sky against the date of the observed event, it was shown, unexpectedly, that the radio source occupied the same position as Jupiter (fig. 2), and exhibited the same change of position as Jupiter, the normal geocentric motion of an outer planet after conjunction. Uranus, also in the field, could not account for the data, nor could two galactic objects near by.

A magnetic tape recording of a transit of Jupiter during an active period revealed more of the nature of the bursts than may be obtained from the pen-and-ink records. The bursts vary in duration from a tenth of a second to almost a second. The same equipment showed terrestrial lightning rarely to last for more than a few tenths of a second. The particular instance recorded also showed a rather smooth background radiation which is not always present.

These observations have all been made at 22.2 mc/sec with the Mills Cross. Some information is available that was obtained at different frequencies with other equipment. During the 1954 occultation of the Crab nebula by the sun (see Year Book No. 53, 1953–1954, pp. 45–46), three occurrences of a "temporary" source were noted. One of these was a particularly obvious event in which a variable source, occasionally stronger than any other source on the record, passed at a sidereal rate through the antenna pattern of the 67.4λ-spacing interferometer (22.2 mc/sec). Simultaneous observations at 38 and 207 mc/sec failed to show this source. The 38 mc/sec records would have shown Jupiter if the intensity of the bursts at this frequency had been greater than 0.008 of that at 22 mc/sec. Recent observations with an interferometer of two single dipoles at 27 mc/sec have shown events attributable to Jupiter, in at least one instance concurrent with observations at 22 mc/sec. Correspondence with Shain in Australia reveals observations of Jupiter at 18 mc/sec; F. G. Smith in England, however, working at 38 mc/sec and 81 mc/sec, has not been able to find Jupiter on his records. It thus appears that the radio emission from Jupiter is confined to the frequencies lower than 38 mc/sec.

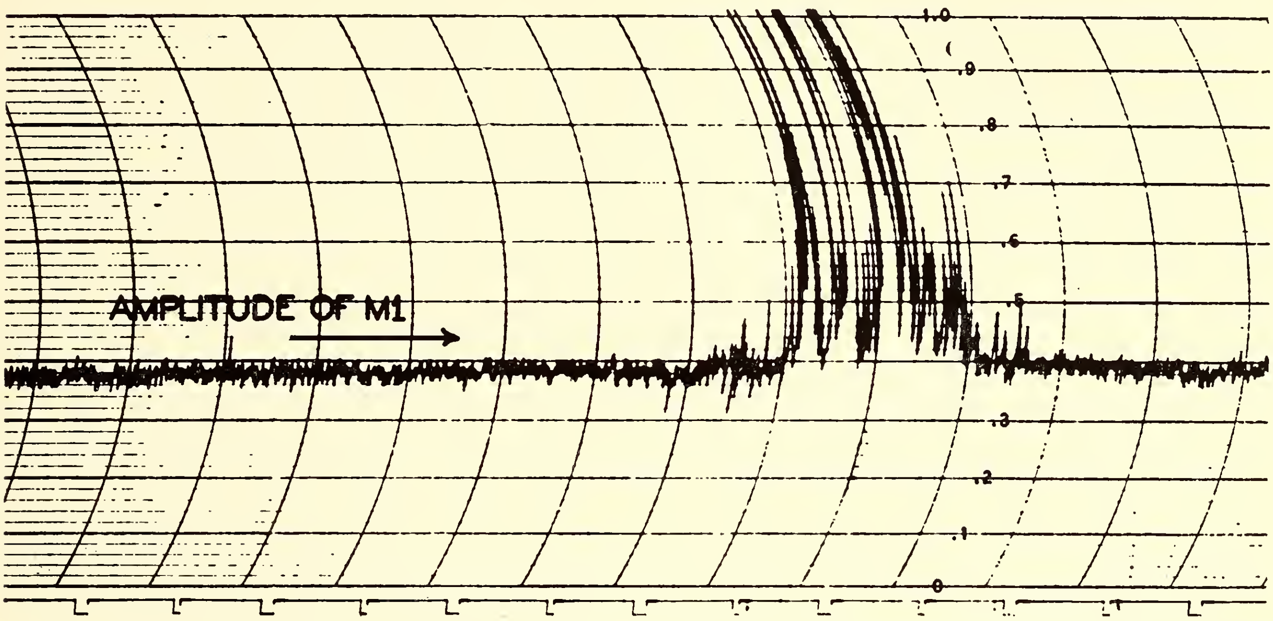

FIG. 1. Intense bursts from the planet Jupiter received by the Mills Cross at 22.2 mc/sec, April 10, 1955. The line at the bottom is interrupted eight times each hour.

The recognition of Jupiter as a radio source, together with the necessary subsequent observations, has occupied a consid-

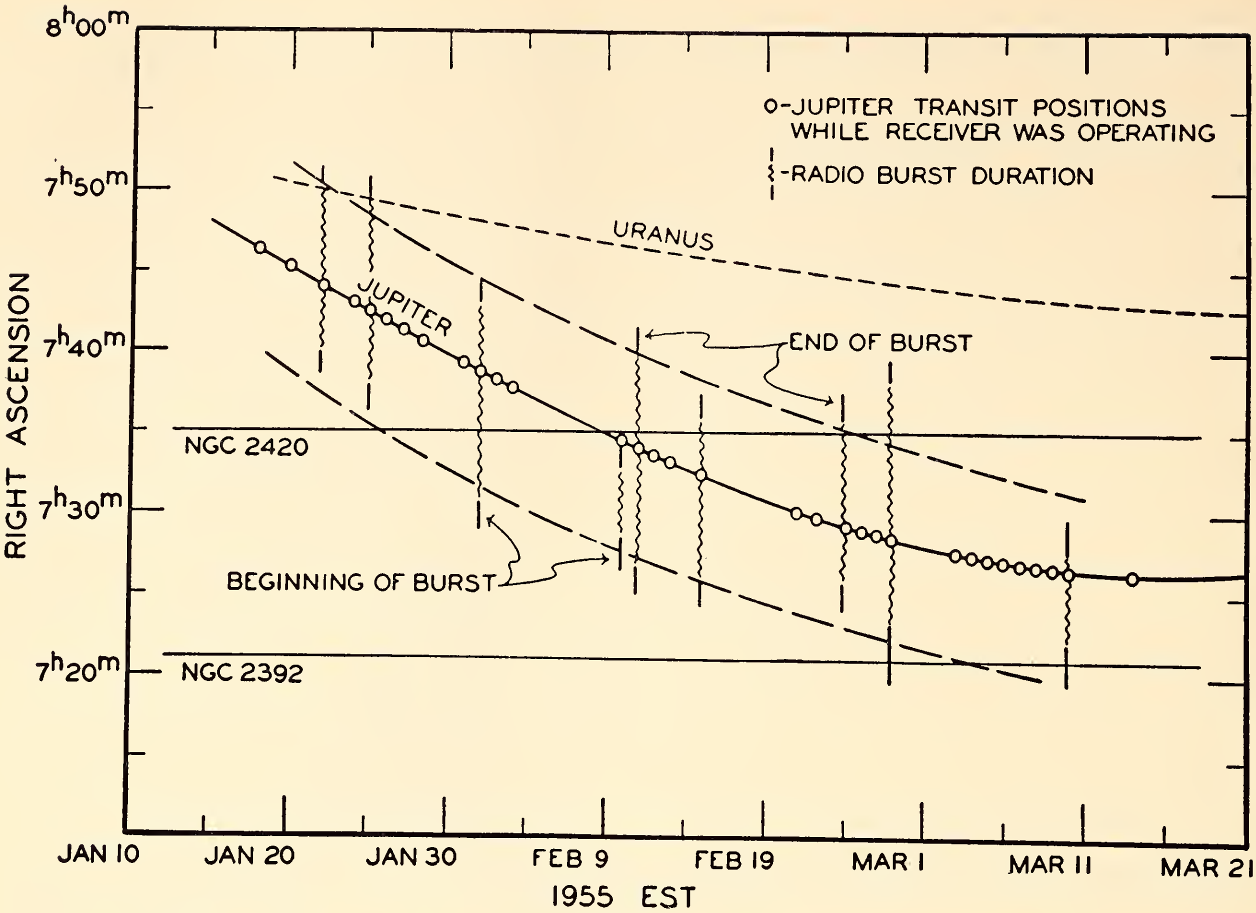

Fig. 2. Change in apparent position of the variable radio sources associated with the planet Jupiter.

erable portion of the observing time of the Mills Cross.

Solar Observations

Observations of radio radiation from the quiet sun at a frequency of 207 mc/sec, on which a preliminary report was made last year, have been continued, and some definite results obtained.

The measurements were made with a radio interferometer and were designed to obtain, as a function of antenna spacing, the amplitude and phase of the sinusoidal receiver output produced as the sun drifted through the beam of the antennas. These two quantities, amplitude and phase, were measured for spacings up to 175 wavelengths, and amplitude alone was measured from 175 to 330 wavelengths.

From these measurements one can deduce, with some confidence, the main features of the distribution of brightness on the solar disk. The most striking feature which appears, and which is also predicted by the theory, is "limb brightening"; that is, for this frequency the sun is brighter near the edge of the disk than it is at the center.

The existence of limb brightening has been demonstrated at higher frequencies at several laboratories, where it has also been found that the radio sun, at the higher frequencies, is not circularly symmetrical, but has more pronounced limb brightening at the equator than near the poles. To check whether or not this deviation from circular symmetry is present at the lower frequency (in this case 207 mc/sec), measurements are now in progress in which the two antennas of the interferometer are placed on a north-south line. The sun is thus analyzed parallel to

its axis rather than parallel to its equator as in the earlier measurements.

Measurements of the position on the sun of sources of extra radiation at times of solar activity have been limited to only a few occasions during the past year. The minimum of the solar activity cycle was reached in April 1954, and the new cycle has not yet contributed much activity.

On one occasion, good position measurements were obtained for a source of enhanced radiation. It was found that the position coincided with that of the leading spot of a high-latitude sunspot group. Such measurements, in conjunction with measurements of other parameters of the radiation (polarization, spectrum, time variation of intensity and position, etc.), and coupled with optical observations of the active regions of the sun, should lead to a better understanding of conditions and processes in the solar atmosphere.

Low-Frequency Results

In order to explore the possibility of extending basic information regarding the spectrum of radio stars, total power surveys were conducted at 20, 15, 12.5, and 10 mc during the spring of 1955. The preliminary results suggested that observations could be made at a frequency as low as 12.5 mc with reasonable freedom from ionospheric interference for approximately 6 to 8 hours during the night. This interval corresponds to the period when F-region ionization is reduced to a level which will not support oblique-incidence propagation of 12.5-mc signals. Observa-

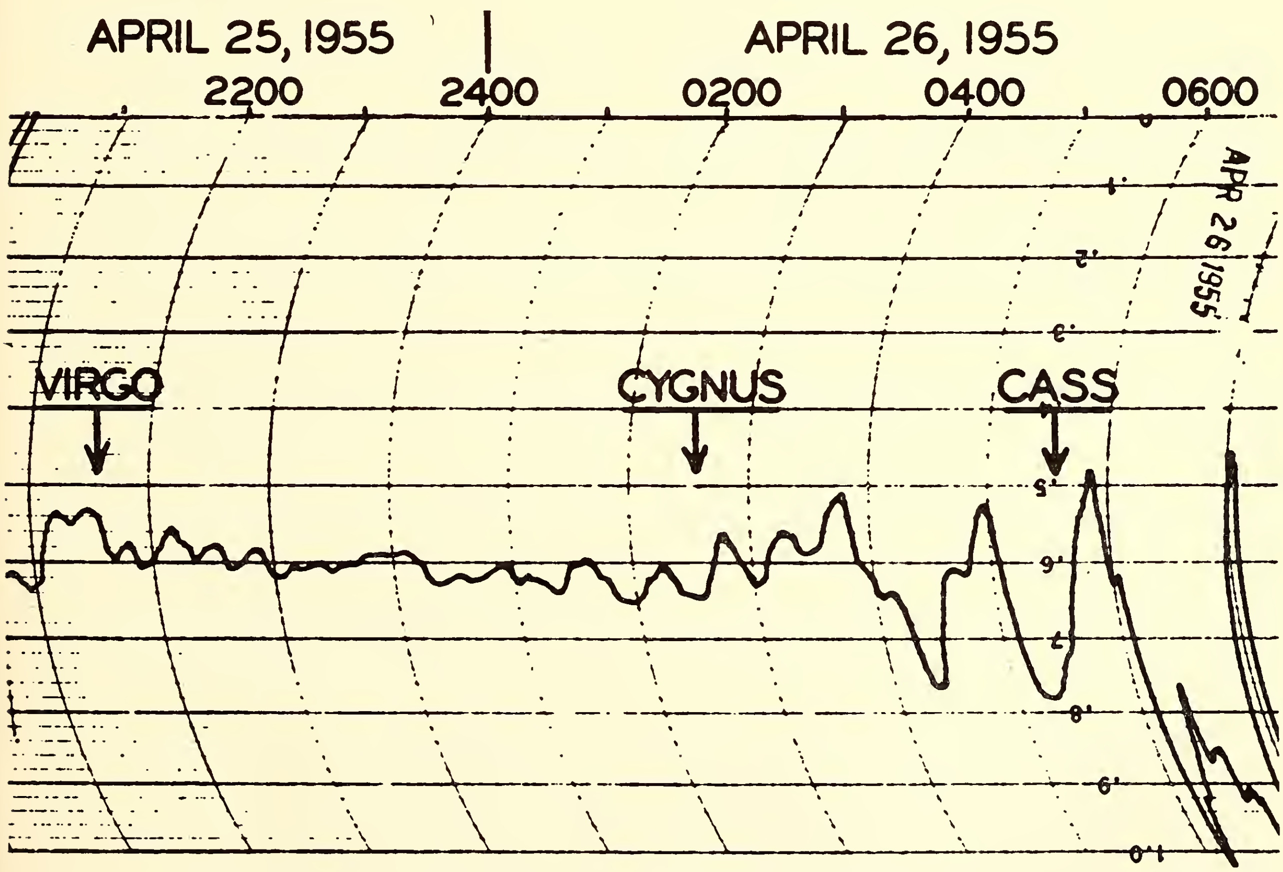

Fig. 3. An unusual record showing Virgo A, Cygnus A, and Cassiopeia A at 12.5 mc, Derwood, Maryland, April 25 and 26, 1955. Such observations are rare because the observing frequency is near the lower boundary of the "window" in our atmosphere for observation of radio "stars." The small "ripples" are observed to progress with sidereal time, and precise measurement of their amplitudes provides new information regarding the spectrum or "radiofrequency color index" of these sources.

tions with an interferometer have led to the detection, at this frequency, of the radio stars Cygnus A, Cassiopeia A, and Virgo A (fig. 3). The observations continue to be of a somewhat probing nature, in order to determine and assess the operating limitations which are imposed by ionospheric interference, absorption, and atmospherics. As a first step, relative intensities of the several sources are being measured. It is hoped that absolute intensities can be calculated, following the determination of specific features of the installation, such as antenna characteristics and receiver band width.

Instrumentation and Facilities

Attempts to achieve a certain degree of standardization among the instruments used for radio astronomy observations have been only slightly successful. This is understandable when one considers the diversified nature of the separate research programs, plus the fact that several foreign investigators have contributed significantly to our instrumental development. It is planned to present detailed discussions of the instruments and their characteristics in separate communications.

Facilities in use during the report year consisted of installations near Derwood, Maryland, and near Seneca, Maryland. For the 200-mc (quiet sun) observations, a lease was concluded for extension of the east-west interferometer line an additional 155 wavelengths, making the total available span approximately 330 wavelengths. Other installations for radio astronomy and related experiments on the grounds of the Derwood field station are: (1) a corner reflector antenna for use at frequencies above 40 mc; (2) three separate installations of interferometers for 27 mc and an interferometer for 12.5 mc.

The multifrequency ionospheric recorder at Derwood was used intermittently for control measurements during periods of radio star scintillations and for demonstration purposes.

The Distribution of Atomic Hydrogen in the Galaxy

H. E. Tatel, M. A. Tuve, and E. T. Ecklund

Theoretical investigations by Van de Hulst in Holland during World War II led Ewen and Purcell at Harvard several years ago to the discovery of the radio emission of cold interstellar hydrogen gas. Their observation of this faint radiation, promptly confirmed in Holland and in Australia, opened a new field of investigation which continues to be fruitful and of great interest to many. In these studies the tool is a special radio receiver tuned to 21 cm wavelength, used with a large parabolic reflector. The immediate objective is to map the distribution of hydrogen gas throughout our galaxy and to explore the relations of this moving gas to motions of the stars and the interstellar dust clouds.

The radio reflector in use at the Department is an obsolete radar "dish" 27 feet in diameter, on loan from the National Bureau of Standards. This reflector has a beam width of 2° by 3½°. The 21-cm radio detection equipment has been improved and has operated well enough for us to make several galactic meridional surveys of the distribution of the intensity of 21-cm radiation. To a first approximation, this intensity is proportional to gas density; self absorption and gas-cloud velocities are later used to obtain numbers more closely related to actual gas densities. These surveys show the gas condensations associated with the "spiral arms" of our galaxy. In particular, we have learned that the local condensation or local arm is not circular with respect to the galactic center, but has a definite inclination. Our sun is on the inner part of this local arm and at a distance of approximately 200 parsecs from the arm center. We are continuing these surveys, particularly toward the center of the galaxy. If the situation is not too complex, we may be able to trace the local arm toward the inner part of the galaxy.

We have also been constructing a multichannel receiver which should enable us

to make our measurements with greater sensitivity, reliability, and speed. A six-channel prototype showed excellent stability. The mechanical work on the system is now complete, and we expect to test the entire fifty-channel system in the early autumn.

The small angular resolving power of our 21-cm radio reflector severely limits our ability to delineate these great cloud structures in space. At the closest point, the intermediate arm of our galaxy has a "thickness" in the plane of the galaxy which is discernibly greater than the resolving power available to us. The more distant arm and the regions toward the center, however, are not resolvable in their angular dimensions with our present reflector. Since it is unquestionably important to examine in detail many parts of the galaxy outside the immediate neighborhood of our sun, and since much higher resolving power would make extragalactic sources at least more accessible to exploration, we have been considering the design problems of larger reflectors.

In co-operation with the Kennedy Company, of Cohasset, Massachusetts, we have found that their basic 60-foot radar paraboloid is rigid enough to serve as the core of an 84-foot paraboloid, which would make a fine instrument. We have also developed the design of a suitable equatorial mount for this reflector. It appears that much larger reflectors, perhaps several hundred feet in diameter, will be needed for any comprehensive studies of hydrogen distribution in objects outside our galaxy, such as the Andromeda nebula.

THE UPPER ATMOSPHERE

B. F. Burke, J. W. Firor, and H. W. Wells

Upper Atmospheric Drifts

The 38-mc observations for radio star scintillations were continued at the River Road site (near Seneca, Maryland) until the spring of 1955. These recordings were forwarded to F. G. Smith, of the Cavendish Laboratory, Cambridge, England, at his request, in order to extend the series of results from the program initiated last year.

Tests conducted at Derwood revealed that radio interferometers could be operated at a frequency around 27 mc with substantial freedom from interference, especially during the night hours. Accordingly the 38-mc receivers were modified to 27 mc, and instruments are in process of operation and testing at the Derwood field station. As a first step, pairs of interferometers are being operated along an east-west base line in order to measure characteristics of the drift velocities. Later, a third instrument will be operated in order to provide a triangulation leading to precise measurements of drift velocities, direction, and blob size.

Considerable interest was expressed at the URSI and Cambridge meetings in 1954 in the results of our observations of F-region traveling disturbances using the triangulation of ionospheric recorders. Most of the important results have been discussed earlier, but additional conferences which are currently under way here with G. H. Munro, of the Commonwealth Scientific and Industrial Research Organization, Sydney, Australia, may reveal some interesting global information regarding traveling disturbances in the upper atmosphere.

Fifty-Megacycle Experiments at Derwood and Bermuda

Using a lobe-switching interferometer technique on the forward-scatter signals from Cedar Rapids, Iowa, an attempt was made to measure the angular size of the scattering area, by observing with antennas at different spacings. Surprisingly, it was found that signals were present in both lobes of the instrument even when the antenna spacing was as small as 2 wavelengths. This suggests the arrival of signals from meteor trails over cones 30° or more in width. Observations at spacings up to 15 wavelengths indicated an increasing tendency for meteor trails to sweep across

two or more lobes of the interference pattern, providing a potential method for measurement of meteor velocity and trail length.

Radio astronomy observations at 50 mc were conducted on a trial basis, using a narrow-band commercial communications receiver with appropriate accessories. Antennas were simple dipoles mounted a few feet above the ground. At 49.9 mc considerable freedom from interference was experienced and the principal radio stars were clearly identified.

After it was learned that several European television stations occupied the spectrum around 50 mc, the antenna beam of the radiometer was directed toward northern Europe. Observations during January 15 through 19 revealed several extended periods of signals whose "on" and "off" times corresponded to the operating schedule of European television stations. The same period included a solar noise storm on January 15 and 16, a solar flare on January 16, and a significant magnetic disturbance on January 17 and 18. Since normal propagation conditions across the North Atlantic were poor during this period, the observations are believed to be evidence of forward scatter from F region of the ionosphere, probably from heights of 600 km or more above the earth. Subsequent observations with greatly improved sensitivity established the fact that there was no continuously observable background signal under normal conditions of undisturbed ionosphere, which is considered to be supporting evidence that the signals received over the path of approximately 3500 miles represented a forward-scatter mechanism from the turbulent F region under disturbed conditions.

These results stimulated interest in conducting additional observations along the Cedar Rapids beam at ranges substantially beyond Washington. With the co-operation of the Office of Naval Research, arrangements were made to conduct an experiment in Bermuda, which is in the path of the Cedar Rapids beam at a distance approximately twice that of Washington. The object of the experiment was twofold: (1) identification of short-period ionization due to meteors (or other sources) at heights above 160 km—a minimum level established by the earth's curvature and the separation between stations; (2) a search for evidence of continuous background signal due to forward scatter from the F region of the ionosphere.

The experiment was conducted in Bermuda from February 8 to 19. This period was characterized by absence of significant meteor showers or magnetic disturbances. A solar noise storm was recorded on February 12, and some interesting records of the principal radio stars were obtained in the course of the investigation of intensity of radiation from the galactic background at 49.8 mc. Results of the experiment demonstrated conclusively that meteors do not generate ionization at heights above 160 km sufficient to reflect oblique-incidence signals at 49.8 mc. Furthermore, there was no continuous background signal of measurable intensity under the conditions which prevailed during the experiment. A few isolated occurrences which appeared to be signals from Cedar Rapids could be interpreted as "two hop" propagation by meteor ionization from E-layer levels. The sensitivity of the radiometer was such that any forward-scatter signals with intensities approaching 1 per cent of the receiver noise level would have been positively identified.

THE EARTH'S CRUST

Seismic Studies

H. E. Tatel and M. A. Tuve

For eight or nine years we have been exploring parts of the continental United States in the hope of learning about the deeper structural characteristics of the earth's crust. During the past several years we have, to some extent, deflected our interest to the study of the passage of seismic waves through a nonuniform medium. In common with others, we had

found that the complexities of the seismogram are not accounted for by simple theory. The complicated ground motion which is called "reverberation" is characteristic of the usual seismogram observed at distances from 20 to 1500 km from the source. We find that this "reverberation" can be explained by surface and volume scattering of seismic waves. The scattering at the surface is accompanied by conversion from one type of wave to another, and accounts in large part for the long duration of the seismogram.

Our model work (see Year Book No. 53, pp. 52–53) has simulated many of these field conditions. This year we were able to produce "multiple" seismograms, using single impulses applied to a table-sized model, which show many of the persistent patterns observed in the field. The demonstrated source of the extra waves producing these quasi-periodic patterns, characteristic of "reverberation," was a set of artificial surface discontinuities on the otherwise homogeneous model. The model gave no "reverberation" with a flat and uniform surface, but when the surface was provided with topographic features (larger than the wavelengths observed), the characteristics of actual field seismograms were at once shown by the records on the model.

We are now satisfied that various types of scattering and conversion account for almost all the ground motion in our seismograms. Except for the first arrival and the totally reflected wave from the lower crustal boundary (at the interface with the mantle), we have found no evidence of coherent signals from any large-scale buried crustal features, such as the basaltic layers which have been widely discussed in the literature of the subject. In our search for these hypothetical crustal layers in previous years, we have used complex arrays of seismometers spread over as much as two kilometers to find coherence in the waves recorded. Most of the "reverberation," however, is quasi coherent, and this method of multiplex observation therefore led to no great improvement in the signal-to-noise ratio. Consequently, in our field work during the past two years we have reverted to the simpler dual-channel system of observation, using two independent seismometers at each of many locations for each explosion. The only large-scale structural feature we have found in the earth's crust is marked by a velocity discontinuity (a change from 6½ or 7 km/sec to 8 km/sec) at a depth of 20 to 45 km below the earth's surface. This is the discontinuity which was first deduced by Mohorovičić in 1905, and is usually referred to by his name.

By 1952 we had found this discontinuity in three regions, Maryland-Virginia, Tennessee-Virginia, and Minnesota. The depths of the discontinuities under the different regions differed. At first glance it appeared that the greater the topographic height, the greater the depth of the discontinuity. The idea of a systematic relation between topographic height and depth of crustal discontinuity was first promulgated by Airy in 1855. He thought that the crust was thicker where it extends higher to form continents, mountains, and plateaus, the greater height being hydrostatically supported, like an iceberg in water, by the thicker crust of uniform density floating deeper in the earth's outer mantle, which has a slightly greater density. Airy's hypothesis was advanced after that of Pratt, who first tried to tie in Everest's observations of the observed deflection of the vertical pendulum near the mountains of northern India with the structure of the crust. Pratt considered the high mountains to be manifestations of a less dense, hence thicker, part of the crust, floating on the denser earth mantle below, but not bulging down into it.

Though the results we obtained in these three different eastern regions seemed consistent with the Airy conception of the earth's crustal structure, there were reasons for dissatisfaction. Three small regions are, after all, a poor sample of an object the size of the earth. The differences in height between the three regions were not great,

and the accuracy of the experiments was not high. Consequently, the results, though indicative, were by no means adequate for generalization.

It is far more difficult to find regions where suitable explosions are available or obtainable than it is to find regions of geological interest. We should like, for example, to explore part of the Great Plains and selected parts of the Rocky Mountains. There is no industrial activity in those regions, however, employing large-scale shots in sufficient number to make an expedition feasible, and special inland explosions for our measurements hardly seem practicable. Our closest approach to the central Rockies was determined by the location of three copper mines in the southern part of the Colorado Plateau and near the Great Salt Lake just west of the Wasatch and Uinta Mountains. These mines were the foci of our expedition in the summer of 1954.

We may take the average topographic height difference between Maryland-Virginia and Tennessee-Minnesota as 2/3 kilometer (2000 feet); the corresponding difference in the depth of the crustal velocity discontinuity obtained from analysis of our seismic data is 10 km. Then if the average topographic height in the western regions were 2 km (6000 feet), the difference in the average crustal depth between east and west would be 3 times as much or 30 km, and we should expect to find in the west a crustal depth of approximately 60 km. There might be a small correction due to the lesser density of the Colorado Plateau sediments. If the elevated parts of the western mountains were 10 per cent lighter than the rocks near the surface in the east, then the expected depth difference would be 27 km, giving a depth of 55 km to the discontinuity.

We made measurements in regions with centers at Silver City, New Mexico; Morenci, Arizona; and Bingham Canyon, Utah. The average topographic height of the regions is 2 km (6000 feet), and we found that the average depth of the velocity discontinuity is 31 km (as for all the values given here, this does not include slight corrections for increase in velocity with depth). Since the elevation is 2 km, the depth of the discontinuity below sea level is 29 km, as compared with 28 km in the Maryland-Virginia region.

If it were only these two regions which could be compared, then, indeed, one could say these two parts of the crust were as Pratt had conjectured. The Minnesota and Tennessee-Virginia results must, however, be taken into account, and the measurements in these regions indicate that the depth of the crustal boundary is about 40 km. Furthermore, in Arizona we had indications of two slightly different depths, to the north and to the south of Morenci.

Prominent critical reflections were observed both north and south of Morenci. The time interval between the first arrivals and the critical reflection, however, was greater north than south of Morenci. This is an indication that the crustal discontinuity is deeper to the north than to the south, the difference being about 7 km. This difference correlated with a difference of 2500 feet in the mean topographic heights, which are 7000 feet and 4500 feet to the north and south, respectively. The ratio of these differences, when compared with the corresponding ratio for 10 km and 2000 feet, respectively, obtained in the east, could be taken to indicate that the density differences between crustal and subcrustal materials in the west may be about 1.8 times the eastern values. Thus, for example, if in the east the density of subcrustal material were 3.3 and that of the crustal material immediately above it 3.1, then in the western regions explored, the corresponding values would be 3.3 and 2.9, respectively. Of course, these density difference calculations are not very precise.

These density values are determined with the implicit assumption that the crust is in isostatic equilibrium. The evidence for this is as follows: In the Arizona–New Mexico region we explored, there are about eight pendulum stations of the Coast

and Geodetic Survey. Though this is an insufficient number from which to draw final conclusions, yet it is interesting to note the values. The mean free-air anomaly is −2 milligals (−20 milligals without regard to sign); the mean Bouger anomaly is −211 milligals; and the mean isostatic anomaly with compensation to 57 km on the Pratt hypothesis (or 28 km Airy) is −15 milligals. The Bouger correction for 2 km of rock is about 240 milligals. Since the Bouger anomaly is almost equal to the Bouger correction, the mean density of the rock is less than that for a rigid earth, and the systems must be "compensated." This is also shown (to some extent) by the low value of the isostatic anomaly. The difference between the latter and the free-air anomaly is small, as usual, and shows the lack of sensitivity of the compensation system in the analysis.

Assume, then, as the few gravity measurements indicate, that this section of the earth is in true hydrostatic (or isostatic) equilibrium. To this assumption a corollary follows: there are no large-scale forces within this section of the earth which change its shape from the equilibrium value. Thus, great topographic height must be associated with earth materials of lesser density at some level between the surface and the center of the earth, probably within a few hundred kilometers of the earth's surface. We have no means, today, by which we can ascertain where these masses of lesser density lie; we may only speculate. The immediate problem is to guess where the less dense rock lies which supports 2 km of Colorado Plateau.

There are, of course, many possibilities. For example, the complete crust, down to 30 km depth, could be 6 per cent less in density. This is roughly the figure obtained from the difference in depth (to the discontinuity) north and south of Morenci. Another possibility is that the less dense rock is concentrated in a fraction of the crustal depth, but its density must be correspondingly still lower. If, for example, this lighter rock constitutes half the crustal depth, its density must average 13 per cent less than that of its eastern counterpart. If, as another example, the lighter rock were in a 10- or 5-km zone, the densities would have to be correspondingly 20 or 40 per cent less—both of which are extreme values. The conclusion follows that if the less dense rock is in the crust, it is probably distributed throughout a depth of more than 10 km. Since the near-surface compressional wave velocity in the Colorado Plateau region is 5.8 km/sec as compared with the eastern value of 6.1 km/sec, it would seem that the rock is less dense in the upper part of the crust.

As an alternative hypothesis, the controlling density differences could exist in the mantle below the Mohorovičić discontinuity. For example, a 1 per cent density difference in 200 km of depth would give the required buoyancy. The precision of the seismic and the gravity data is insufficient to detect this small difference.

The data we have obtained in the past few years serve to give a rough picture of the earth's crust under the North American continent. It is an inhomogeneous rock layer extending from the surface sediments to a depth of 20 to 45 km. Though we know, from the gravity data, that the crust is in approximate isostatic equilibrium, we do not know where the changes in density are located; they may even be below the crust, in the mantle. From our recent results, it can be seen that crustal properties vary appreciably over an entire continent. Airy's or Pratt's hypothesis can be used to describe a part of a continent, but not the whole.

It is a pleasure to acknowledge the fine co-operation of the many men of the Kennecott Mining Company and the Phelps Dodge Company. We are grateful to them for their courtesies and helpfulness in arranging for the measurements of their explosions in the midst of their complex mining operations.

Rock Magnetism

J. W. Graham

Important and encouraging progress has been made in the problem of determining the extent to which it will be possible to trace the history of the changes in the earth's magnetic field in geologic time.

In our earlier work we had demonstrated a regional consistency in the directions of magnetization of sediments in the Appalachian Mountains (see Year Book No. 48, 1948–1949, p. 8). These directions were such that it seemed clear that at one time the earth's magnetic field was not oriented as it is today. Our efforts to verify this interesting possibility by finding the same magnetizations in other rocks outside the Appalachians were unsuccessful.

In June 1954 Clegg and others from the Imperial College of Science and Technology in London reported a regionally consistent pattern in the magnetization direction of late Paleozoic and Triassic rocks in England. From these it was possible to conclude, tentatively, either that England had rotated 34° since Triassic time, or that the magnetic poles formerly appeared on the earth in the vicinity of Kamchatka and southeast of Brazil. It was immediately obvious that these interpretations should be examined by means of studies of rocks of comparable ages in other continents.

In the months of March, April, and May 1955, with our fully equipped field truck and with assistance from the U. S. Geological Survey on the problem of selecting sites and in some of the sampling, we studied the magnetizations of Triassic and Permian sediments in Maryland, New Mexico, Arizona, and Utah. It was found that as a group the Triassic sediments have a pattern of magnetization that is not greatly different from what would be produced by the earth's field today, but in contrast, the Permian sediments have a great concentration of magnetization directions far removed from the present field.

To a reasonably good approximation, the earth's magnetic field today can be represented by a dipole. On the surface of a sphere containing a dipole at its center it is possible to locate the magnetic poles (where the lines of force are vertical at the surface) by measurements, at any chosen point, of the horizontal direction of the lines of force and their downward slope. The magnetization directions of the various exposures of the Triassic sediments in England and the Permian sediments of the southwestern United States, when analyzed on the basis of this simple dipole picture, give a number of points on the earth where the magnetic poles could be considered to have been, to account for the observed magnetizations. The startling fact is that the group of points derived from the magnetizations found in England are overlapped by the points determined from the United States. In other words, the measurements indicate that these rocks in England and the United States were magnetized long ago when the earth's magnetic field was not in its present orientation; it seems also that since that time England and the United States have maintained their present relative positions. The center of the group of pole locations falls at about 50° W and 45° S (130° E and 45° N). Even though it seems highly unlikely that these determinations would agree unless these simple assumptions were correct, nevertheless, the inferred average positions of the magnetic poles will have to be confirmed by studies in still other continents. The lack of agreement of the Triassic samples in the United States is reminiscent of many similar findings in other rock magnetism studies. The most readily plausible explanation is that the original magnetizations of these beds have been overprinted by the earth's present field.

It is interesting to consider the implications of the magnetic poles' having once been in these significantly different locations. From two distinct lines of argument there is justification for believing that the present-day near coincidence of the mag-

netic and geographic axes is not fortuitous. Magnetization studies in rocks up to 50 million years old locate the magnetic poles in clusters about the geographic poles. Theoretical studies of the probable pattern of fluid motions in the core (where the magnetic field is believed to have its origin) indicate that the earth's magnetic field, when observed over a long period of time, should be symmetrical about the geographic axis. Thus it seems reasonable to believe that when these rocks were magnetized, the geographic axis was about 45° away from its present position. On the basis of this picture, it can be said that about 200 million years ago the equator crossed lower California, west Texas, Massachusetts, Gibraltar, Kenya, and Tasmania.

An interesting possibility that is suggested by the magnetizations of these rocks is that the sense of the earth's magnetic field has reversed; i.e., the north and south magnetic poles have exchanged positions. But this possibility cannot be confirmed solely on the basis of observations of the sense of magnetization of rock samples, because it is known that in nature the direction of magnetization of some specimens under appropriate circumstances can undergo a spontaneous self-reversal of direction. Criteria for determining whether or not a given specimen has undergone the self-reversal process have not yet been established; and thus, even though the sense of magnetization of many samples of Permian and Triassic rocks implies reversals of the earth's field, the possibility remains that actually the field has maintained a constant sense. The whole problem remains as one of the most interesting and baffling in the subject of rock magnetism.

At the beginning of the report year, we made some observations bearing on the problem of the overprinting of original magnetizations. In some New York state Devonian limestone beds, which by very localized slumping had been greatly deformed very soon after their deposition while they were still essentially unconsolidated and plastic, we observed that the magnetization directions throughout the deformed structures were practically uniformly oriented, and not in the direction of the earth's present magnetic field. Using the techniques developed by Dr. P. H. Abelson, of the Geophysical Laboratory, the amino acids present in the fossils of the limestone were isolated and identified. Although the concentration of amino acids amounted to only a few parts per million, the nature of the assortment of identified species strengthened the belief, earlier advanced on the basis of geological evidence, that these particular beds had never been subjected to extensive heating. Thus, from this and from other experiences we must conclude that lack of elevated temperatures during the history of a sediment may be a necessary but is not a sufficient condition for the preservation of primary magnetizations acquired at the time of deposition.

Isotope Dating of Ancient Minerals

L. T. Aldrich, G. L. Davis,[1] G. R. Tilton, and G. W. Wetherill

In the report of this group one year ago it was mentioned that our initial aims of measuring, comparing, and evaluating mineral ages by the different naturally occurring radioactive elements uranium, thorium, rubidium, and potassium, all extracted from the same rock sample, had been partially achieved with the measurements on the minerals in the Quartz Creek region, Gunnison County, Colorado. The process of measuring comparative ages and evaluating the results has been extended this year to several other localities, has been applied to several new minerals for the different elements, and has seen the measurement of potassium-argon ages for most of the minerals to which our methods for rubidium-strontium had previously been applied. As a result of this extension, we believe that we are now ready to begin

[1] Geophysical Laboratory, Carnegie Institution of Washington.

intensive studies of ways in which mineral ages can be applied most profitably to geological problems.

It was further pointed out last year that the work on minerals from Quartz Creek was not conclusive, since no reliable age could be assigned to any of these minerals examined in the laboratory. The reasons why the results were not conclusive are worth giving here, to serve as a background for examining the work of the past year. The age of a mineral can be measured if (*a*) the relative amounts of parent and daughter isotopes can be determined, (*b*) the amount of daughter isotope initially present in the mineral at the time the mineral was formed can be determined, (*c*) the decay scheme and decay constants of the parent isotope are accurately known, and (*d*) there has been no loss or gain of parent or daughter isotopes since the mineral was formed. From our work of the past four years we are confident of our ability to determine the relative amounts of parent and daughter isotopes, and to make accurate corrections for the daughter isotope which was present when the mineral was formed, for all the minerals studied. The only minerals which appear to satisfy the remaining requirements are uraninites and zircons from pegmatites. This is due to the facts, first, that the decay constants of uranium are well established, and, secondly, that the decay rates of the two parent isotopes are different. Thus, when the ages determined from the two uranium systems agree, it is very improbable that geochemical processes involving loss or gain of either parent or daughter isotope have taken place. The equality of these two uranium ages is our criterion of a reliable age. Measurements on three minerals from the Quartz Creek region satisfied all but this final criterion, and thus fail to give the complete data desired in mineral age comparisons.

The difficulties with the potassium and rubidium methods are more basic at this stage, since there are unresolved differences of the order of 40 per cent in the values reported for both the beta-decay constant of Rb^{87} and the electron capture decay constant of K^{40}. Since Rb^{87} and K^{40} occur in the same mineral and have different half lives, it is important that these differences be resolved so that ages derived from the decay of these two isotopes may be used in the same way as those from the two uranium isotopes to determine reliable ages. Further, suitable minerals containing K^{40} and Rb^{87} are considerably more common than those containing the two uranium isotopes, so that the establishment of the reliability of ages from the decay of potassium and rubidium is of primary importance.

The work of the group this year may be summarized in the following statements:

1. The age studies of minerals in the Quartz Creek (Colorado) area have been extended so that they are probably more complete than those at any other locality. This work has demonstrated a pattern of consistency among the rubidium-strontium ages, and these were determined for minerals containing amounts of rubidium ranging from 0.012 per cent to 2 per cent in different samples. The work has also demonstrated a similarly consistent pattern among the potassium-argon ages of the micas from this region.

2. Measurements of rubidium-strontium and potassium-argon ages have been completed on micas and feldspars from three areas where the uranium-lead ages fulfill the requirements of reliability set forth above. The uraninite from one of these areas was also analyzed. These measurements show the same consistency in rubidium-strontium ages for all minerals and potassium-argon ages for micas that was found at Quartz Creek. Some estimate of the problems due to the uncertainties of the decay scheme or to the retention of parent and daughter elements may be made as a result of these measurements.

3. Seven rocks containing both mica and feldspar have been studied, including some of those mentioned above, in which a comparison of the ratio of radiogenic argon to

potassium in each mineral may be made. In every case this ratio is higher for the mica than for the feldspar, and we have not found any consistency between the ratio for the mica and that for the feldspars.

4. Comparisons of rubidium-strontium and potassium-argon ages have been made on micas from other granites and pegmatites where the rubidium age had been previously determined. The same relation has been found between these two ages for this group of micas as for those from the locations where more extensive work has been done.

5. Further uranium, thorium, and lead measurements on zircons, microlites, and monazites have demonstrated difficulties in using these minerals to determine unambiguously the age of a mineral.

The measurements will be discussed by location, when sufficiently extensive work has been completed to do so, and by rock and mineral type, when conclusions may be better drawn from this form of presentation.

Quartz Creek Region, Gunnison County, Colorado

Determinations of twenty-nine independent ages of minerals, many in duplicate, from the Brown Derby pegmatite and the granite of the Quartz Creek region have been completed. The extent of the work on this region was encouraged by the availability of very complete suites of minerals from both pegmatite and granite, which made possible the comparisons by the different decay schemes. The data will be presented in the form of apparent ages calculated from the ratio of parent to daughter, since this is the only practical way to show comparisons by decay systems with different decay rates. The decay rates and isotopic abundances assumed in the calculations of the ages are given in table 1.

The uranium, thorium, and lead data have been supplemented this year with the analyses of monazite and microlite from the pegmatite. In table 2 these data are compared with those previously found for the zircon from the granite. The isotopic abundance of lead extracted from a feldspar in the pegmatite was used for the common lead correction to that found in the zircon; the isotopic composition of this feldspar lead is: $Pb^{206}/Pb^{204} = 16.72$; $Pb^{207}/Pb^{204} = 15.30$; $Pb^{208}/Pb^{204} = 35.73$.

TABLE 1

Decay rates and isotopic abundances of parent isotopes used in this report

Isotope	Decay rate	Isotopic abundance
K^{40}	$\lambda_\beta + \lambda_K = 5.59 \times 10^{-10}$ yr^{-1} $\lambda_K/\lambda_\beta = 0.10$	1.22×10^{-4} gr/gr K
Rb^{87}	$\lambda_\beta = 1.13 \times 10^{-11}$ yr^{-1}	0.283 gr/gr Rb
Th^{232}	$\lambda_\alpha = 4.99 \times 10^{-11}$ yr^{-1}	1 gr/gr Th
U^{235}	$\lambda_\alpha = 9.71 \times 10^{-10}$ yr^{-1}	0.0073 gr/gr U
U^{238}	$\lambda_\alpha = 1.54 \times 10^{-10}$ yr^{-1}	0.9927 gr/gr U

It is evident that, in the absence of any correlative evidence, these results give no unambiguous values for the age of either the granite or the pegmatite. If one knew the age of the region, it would be possible to postulate geochemical events to explain the results given, but the results do not help in evaluating decay constants and geochemical alterations in the potassium and rubidium minerals, as we are able to do at other locations. It is possible that if finally the potassium and rubidium results are proved to be valid, they may be of considerable help in unraveling the parent-daughter fractionations which have

TABLE 2

URANIUM-LEAD AND THORIUM-LEAD AGES, QUARTZ CREEK REGION, GUNNISON COUNTY, COLORADO

Rock and mineral	Age (million years)			
	U^{238}-Pb^{206}	U^{235}-Pb^{207}	Pb^{207}-Pb^{206}	Th^{232}-Pb^{208}
Granite:				
Zircon	930	1130	1540	515
Pegmatite:				
Monazite	1590	1410	1170	995
Microlite	915	1050	1350	...

occurred in the uranium and thorium minerals.

The ages by the Rb-Sr and K-A methods are given in table 3. Several facts in table 3 should be emphasized. First, although there is a consistency in the Rb-Sr ages, there are differences of the order of 20 per cent, as yet unexplained, in the ages found for all minerals from different parts of the pegmatite. A similar and even better consistency among the K-A ages of the micas (lepidolite, biotite, muscovite) is demonstrated. A sharp discrepancy between the K-A ages of the micas and of the feldspars is apparent and can be most easily interpreted as due to argon loss in the feldspars. The micas appear to retain the argon evolved from the decay of the amount of potassium they contain. This discrepancy between K-A ages of micas and feldspars is most plainly shown in the results for microcline B and the muscovite intergrown with it. Though the Rb-Sr ages of the two are in relatively good agreement, the K-A ages are greatly discordant. The Rb-Sr ages of the feldspars in granite and pegmatite are the first reported for these minerals. The fact that they are reasonably concordant with those for the micas gives added confidence in the consistency of Rb-Sr ages generally. The ratio of the Rb-Sr age to the K-A age of the five micas is 1.24 ± 0.04, showing a gratifyingly consistent ratio between the ages measured by

TABLE 3

POTASSIUM-ARGON AND RUBIDIUM-STRONTIUM AGES, QUARTZ CREEK REGION, GUNNISON COUNTY, COLORADO

Rock and mineral	Age (million years)	
	K-A	Rb-Sr
Granite:		
Biotite	1380	1620
Feldspar	1040	1820
Pegmatite:		
Lepidolite containing microlite	1460	1830
Microcline A	870	....
Microcline B	880	1590
Muscovite intergrown with microcline B	1300	1680
Lepidolite, coarse books (lilac)	....	1730
Lepidolite, fine-grained (white)	1400	1690
Lepidolite, medium-grained (lilac)	....	1750
Lepidolite, fine-grained (lilac)	....	1900
Lepidolite, coarse in quartz-cleavelandite matrix from same hand specimen as fine lilac	1380	1750

both systems for these minerals. Thus, although the minerals from the Quartz Creek region have been something of a disappointment in producing the desired kind of comparison with good uranium ages, the measurements at this locality have shown that there is good reason to be hopeful about the K and Rb decay schemes because of their self-consistency and reasonably constant relation with each other. From our results on the other pegmatites where good uranium ages are available, we would say that the age of this pegmatite and granite is 1400 ± 150 million years.

Comparison of Ages of Rocks with Reliable Uranium Ages

The experience with the Quartz Creek area demonstrated the difficulties of working with minerals by the Rb-Sr and K-A methods when the age of the rock is unknown. Accordingly, efforts have been made to secure reliable U-Pb ages with which to compare the Rb-Sr and K-A determinations. Unfortunately, most uranium minerals such as monazite, granitic zircon, and microlite usually give discordant U^{238}-Pb^{206} and U^{235}-Pb^{207} ages, and are therefore not usable for this purpose. Uraninite, however, usually does give reliable ages, and several suites of minerals from the same pegmatites containing uraninite, feldspars, and micas have been collected. Work has just been started on the suites, and complete results are available for only one, from the Bob Ingersoll Mine, Black Hills, South Dakota.

The U-Pb ages agree within experimental error at 1600 million years, as shown in table 4. This may be taken to be the true age of the pegmatite with a good degree of confidence.

Results of replicate analyses of lepidolite from this pegmatite are shown in table 5. Sample A was supplied by L. H. Ahrens and analyzed several years ago. Sample B was collected in the summer of 1954 by members of the group. The difference between the ages found for samples A and B may be attributed to improvements in analytical techniques during the past several years.

TABLE 4

AGES OF MINERALS FROM THE BOB INGERSOLL MINE, PIT NO. 1, KEYSTONE, SOUTH DAKOTA

Mineral	Age (million years)			
	U^{238}-Pb^{206}	U^{235}-Pb^{207}	Pb^{207}-Pb^{206}	Th^{232}-Pb^{208}
Uraninite	1580 ± 30	1600 ± 20	1630 ± 30	1440 ± 50
	Rb(%)	Sr^{87}(ppm)	Rb-Sr age (m.y.)	K-A age (m.y.)
Muscovite	0.409	28.2	2130	1690
Microcline	0.679	43.0	1970	1210
Lepidolite	1.11	73.2	2050	1500

TABLE 5

REPLICATE ANALYSES OF LEPIDOLITE FROM BOB INGERSOLL MINE, PIT NO. 1, KEYSTONE, SOUTH DAKOTA

Sample	Rb(%)	Sr^{87}(ppm)	Rb^{87}-Sr^{87} age (m.y.)	K^{40}-A^{40} age (m.y.)
A	1.19	72.6	1890	...
B:				
1	1.08	72.9	2080	1500
2	1.10	72.5	2040	
3	1.14	74.9	2025	

Comparisons of Rb-Sr and K-A ages of lepidolite, muscovite, and microcline from this pegmatite are also shown in table 4. The Rb-Sr ages are consistently about 30 per cent higher than the "true" age, 1600

million years, very likely indicating an incorrect decay constant for Rb^{87}. The K-A ages of the three minerals are not in as good agreement, the feldspar age being characteristically lower than the two mica ages. The two mica ages, however, do not agree very well between themselves in this case. It must be emphasized that the K-A ages depend on the branching ratio used, and that it is possible to choose reasonable branching ratios which would bring either the muscovite or the lepidolite age into agreement with the uraninite age. It is not possible to bring the feldspar age into agreement without using an unreasonably low value for the branching ratio. Perhaps the most likely explanation of the discrepancies is that the true branching ratio is about 0.105 and that the lepidolite has lost a small amount of its argon, while the feldspar has lost a larger amount.

TABLE 6

AGES OF MINERALS FROM FISSION MINE, WILBERFORCE, ONTARIO

Mineral	Age (million years) K-A	Rb-Sr	
Biotite	1015	1210	
Antiperthite	925	....	
	U^{238}-Pb^{206}	U^{235}-Pb^{207}	Pb^{207}-Pb^{206}
Uraninite *	1077	1050	1035

* Nier, *Physical Review,* vol. 55, p. 153 (1939).

Two other sets of comparisons between reliable U-Pb, Rb-Sr, and K-A ages are shown in tables 6 and 7. In these cases the uranium and thorium ages have not yet been determined in this laboratory, and the comparisons are therefore with the work of other investigators. Again the Rb-Sr ages are seen to be higher than the "true" ages. Using a branching ratio of 0.100, the K-A ages of the micas are in rather good agreement with the U-Pb ages; the data do not, however, exclude other values for the branching ratio.

TABLE 7

AGES OF MINERALS FROM BIKITA, SOUTHERN RHODESIA

Mineral	Age (million years) K-A	Rb-Sr		
Lepidolite	2570±80	3200±170		
	U^{238}-Pb^{206}	U^{235}-Pb^{207}	Pb^{207}-Pb^{206}	Th^{232}-Pb^{208}
Monazite *	2675	2680±15	2680±30	2645±25

* Holmes, *Nature,* vol. 173, p. 612 (1954).

Other Potassium-Argon and Rubidium-Strontium Comparisons

In addition to the comparative age measurements reported above, several more have been made in which Rb-Sr ages are compared with K-A ages only. These are shown in table 8. Again it is seen that the Rb-Sr ages are consistently higher than K-A ages. The Bonneville sample is the oldest yet found in the United States. The Jakkalswater samples are another example of the feldspar-mica discrepancy.

TABLE 8

COMPARISON OF K-A AND RB-SR AGE DETERMINATIONS

Locality	Mineral	Age (million years) K-A	Rb-Sr
Bonneville, Wyo.	Lepidolite	2390	3050±200
Bagdad, Ariz.	Lepidolite	1510	1885±100
Jakkalswater, Cape Province, Union of S. Africa	Muscovite	1015	1170±120
	Microcline	605	....

Radiogenic Calcium

One of the difficulties encountered in the measurement of argon ages arises from the lack of a precise value of the branching ratio $\lambda_K/\lambda_{\beta^-}$. One way to measure this branching ratio would be to measure the ratio of radiogenic calcium to radiogenic argon in a potassium mineral. Subject to

the usual assumptions, this ratio will be equal to the branching ratio, regardless of the age of the mineral. Measurement of the radiogenic calcium is difficult because of the high abundance of normal calcium in most minerals. Very few minerals are usable for this measurement, from among which we have selected lepidolite.

This work is still in a preliminary stage. Two measurements have been made on lepidolite from Bikita, Southern Rhodesia. The calcium in the mineral was about 25 per cent radiogenic. Because of difficulty in measuring absolute isotopic abundances of calcium, we have not yet succeeded in making an accurate measurement of the concentration of radiogenic calcium in this mineral.

At present we are preparing a "spike" containing an accurately weighed mixture of Ca^{42} and Ca^{48}. A known amount of this mixture will be added to the mineral as it goes into solution. Since the absolute Ca^{42}/Ca^{48} ratio in this mixture is known, it will then be possible to correct for isotopic fractionation in the source as well as for effects which appear to be fractionation due to the characteristics of the electron multiplier used as an ion detector. By using Ca^{44} as an index of normal calcium, the concentration of radiogenic Ca^{40} can then be determined absolutely. It is our hope that use of this spike will permit measurement of the branching ratio by this method.

Ages from Zircons

We have based our hopes of determining uranium-lead ages for granites almost entirely on the mineral zircon. Although zircon is but a few hundredths of one per cent abundant in a typical granite, it usually contains about 0.1 per cent uranium, which accounts for approximately half the uranium in the rock. Furthermore, it has been found that virtually all the lead in zircon is radiogenic (lead which has resulted from the decay of uranium and thorium), thus making corrections for primary lead (lead present in the mineral when it was originally formed) unnecessary or unimportant. There is no other common mineral constituent of granites which can rival zircon either in its high uranium content or in its low primary lead content.

Other laboratories are currently testing simple methods of using zircons for age determination. One such method uses the alpha activity of the mineral as an index of its uranium-plus-thorium content and derives an age from the ratio of the alpha activity to the total lead content, since all zircons studied to date by the mass spectrometer show insignificant amounts of primary lead. This is called the "alpha-lead" method. A second method is based on the amount of damage suffered by the crystal structure of the mineral from the alpha bombardment it has undergone. Any mineral lattice suffers a dislocation of 10^3 to 10^4 atoms for each alpha decay which takes place within the lattice. Following the dislocation, the shattered portions may either anneal and convert once more to the original crystal structure or remain as a glass. We encounter both conditions in age work, monazite being an example of a mineral which anneals itself and zircon being an example of one which does not. Minerals showing damage from alpha decay are said to be "metamict." The X-ray age of a zircon is obtained by measuring the present rate of damage to the crystal from its alpha activity, and measuring the total damage by X-ray data. The ratio of these two quantities gives an age.

Because of the importance of zircon to our own program of age comparisons, as well as the widespread attention given to the mineral in other laboratories, we have done considerable work on this mineral. Our analyses involve the determination of uranium, thorium, lead, and the isotopic composition of the lead. The results of the analyses completed to date appear in table 9.

TABLE 9

AGES OF ZIRCONS

Locality	Grain size	Age (million years)			
		U^{238}-Pb^{206}	U^{235}-Pb^{207}	Pb^{207}-Pb^{206}	Th^{232}-Pb^{208}
Tory Hill, Ont.	1–2 mm	1030	1055	1090	390
	200–350 mesh	940	960	1015	...
Cape Town, S. Africa	200–350 mesh	330	355	525	237
Bagdad, Ariz.	200–350 mesh	630	770	1210	270
Quartz Creek, Colo.	200–350 mesh	930	1130	1540	515
Ceylon	1–2 cm	540	544	555	538
Natural Bridge, N. Y.	1–2 cm	1025	1065	1140	...

It is obvious from inspection of the table that gross discrepancies are often present in the calculated ages. This fact immediately forces us to inquire which, if any, of the ages is correct. For a possible answer to this question we turn to Rb-Sr and K-A age determination on minerals from the same granites as three of the zircons in table 9. These comparisons are given in table 10, where the Pb^{207}-Pb^{206} ages from table 9 are repeated for reference. It will be noticed in table 10 that the K-A ages of the three potash feldspars are all lower than those of the micas from the same granite, a pattern which has persisted through all our measurements. It is also apparent that the Rb-Sr and the K-A ages agree more closely with the Pb-Pb ages of the zircons than they do with the respective U-Pb or Th-Pb ages, which are generally lower than the Pb-Pb ages. From this we may conclude that the Pb^{207}-Pb^{206} ages for the zircons indicate more nearly than do the others the time elapsed since these three granites were formed. The fact that the U-Pb ages are low is extremely important and may yield valuable information once the factors which cause the discrepancies are known. If our interpretations are correct, a loss of lead or a gain of uranium must have occurred in the zircons under such conditions that the K/A and Rb/Sr ratios of the micas were affected very little if at all. In the coming months it is anticipated that part of our efforts will be directed toward gaining some understanding of this problem.

TABLE 10

AGE COMPARISONS OF MINERALS SEPARATED FROM GRANITES

Locality	Mineral	Age (million years)		
		Pb^{207}-Pb^{206}	Rb-Sr	K-A
Cape Town, S. Africa	Zircon	525	....	....
	Biotite	....	820	560
	Potash feldspar	....	....	200
Quartz Creek, Colo.	Zircon	1540	....	....
	Biotite	....	1620	1380
	Potash feldspar	....	1820	1040
Bagdad, Ariz.	Zircon	1210	....	....
	Muscovite	....	1750	1480
Uncompahgre, Colo.	Biotite and xenotime	1650	1650	1410
	Potash feldspar	....	....	1030

A second reason for believing that the U-Pb ages are low is found in the data of

table 9. The Th-Pb ages for the Tory Hill and Bagdad granites, which are Pre-Cambrian (that is, older than approximately 500 million years), are impossibly low. Since these Th-Pb ages are low, it appears logical to assume that the U-Pb ages have been lowered in these instances by the same mechanism, without specifying anything about its nature. The two zircons from Tory Hill in table 9 have unknown field relations, and it is not possible to say that the U-Pb age of the fine-grained zircon is low, although there is an indication that this might be true.

As a result of all our work with zircons to date we may say that discrepancies between U-Pb and Pb-Pb ages are often encountered, and that in such cases one must interpret the data in order to decide on an age. Our interpretation is that the Pb^{207}-Pb^{206} age is nearer to the true age for these zircons. The X-ray age agrees with the ages given in table 9 for the Ceylon zircon, but gives a value of 700 million years for the Natural Bridge zircon and 250 million years for the Cape Town zircon. These X-ray ages were measured by Professor H. D. Holland, of the Geology Department of Princeton University. It was not possible to obtain X-ray ages for the remaining samples. It is known that zircons may be annealed in the laboratory when they are heated to temperatures in the neighborhood of 900° C. Any annealing of a zircon which takes place in nature will result in too low an X-ray value for total damage, and thus a low age. This may be the cause of the low X-ray ages.

The alpha-lead ages resemble very closely the U^{238}-Pb^{206} ages in table 9. Accordingly, in a number of cases they depart substantially from what we consider the true ages of the minerals to be. We believe that the low U-Pb ages point to information regarding the history of the zircons which we may eventually be able to interpret with the aid of laboratory experiments designed to test the conditions under which uranium and thorium may be gained or lead may be lost from zircons. In the present ambiguous state of the zircon age method, we believe that no age information for a zircon should be discarded, and that the simple age methods are of doubtful validity until complete isotopic work has been done on many more specimens.

We have given the opinion in past reports that lead loss or uranium-plus-thorium gain may occur more easily for small zircons than for large ones, and that the discrepancies between the U-Pb and Pb-Pb ages may be related to the crystal size. This relation is less apparent in the data now at hand. The fine-grained zircon from Tory Hill gives a discrepancy between U-Pb and Pb-Pb ages which closely resembles that given by the large single crystal from Natural Bridge. More work is needed on this problem, particularly with large crystals.

Ages from Monazites

Two new monazite age determinations were completed in the past year. Acid washing experiments were made on the four monazites for which we have complete age determinations, which demonstrated some interesting nonuniformities in two of the samples with regard to the distribution of uranium, thorium, and lead. Tables 11 and 12 summarize the results of this work. The acid washing data of table 12 were obtained by crushing samples of the crystals to a grain size smaller than 60 mesh, then treating the powders for 15 minutes in a cold 6M solution of hydrochloric acid, and analyzing the resulting solutions for uranium, thorium, and lead.

Inspection of tables 11 and 12 shows that these nonuniformities tend to correlate with certain features of the U-Pb—Pb-Pb age pattern. The Houtenbek and Quartz Creek (Colorado) monazites, with U-Pb ages which are greater than their respective Pb-Pb ages, show excesses of soluble ura-

nium and thorium relative to the amounts of the two elements in the total samples. These two monazites likewise show excesses of acid-soluble Pb^{206} (daughter of U^{238}) over Pb^{208} (daughter of Th^{232}) as compared with the relative amounts of these isotopes in the total sample. In contrast, the Goodhouse monazite, for which the U-Pb and Pb-Pb ages agree, shows these trends to a much smaller extent. In general, the Goodhouse monazite, which gave satisfactory age results, appears to be considerably more uniform with respect to the distribution of uranium, thorium, and lead in its lattice than are the other two monazites, which gave discrepant results. High U-Pb ages will result from the loss of uranium by a mineral, and it is accordingly believed that the high uranium content of the acid-soluble phases of the Quartz Creek and Houtenbek monazites is indicative of such losses. As was stated in a previous section, the true age at Quartz Creek is believed to be 1400 ± 150 million years, so that this monazite has suffered additional fractionations besides the recent loss of uranium. The agreement of the Th-Pb and Pb-Pb ages in the Houtenbek monazite, 940 and 930 million years respectively, is believed to establish the age of this mineral at 935 ± 50 million years.

We take pleasure in expressing our indebtedness for field advice in collecting

TABLE 11

AGES OF MONAZITES

Locality	Age (million years)			
	U^{238}-Pb^{206}	U^{235}-Pb^{207}	Pb^{207}-Pb^{206}	Th^{232}-Pb^{208}
Quartz Creek, Colo.	1590	1420	1170	995
Goodhouse, S. Africa	930	920	880	900
Houtenbek, S. Africa	1400	1210	930	940
Steenkampskraal, S. Africa	1090	*	*	990

* Primary lead correction for the Pb^{207} content of the monazite was too high to permit accurate calculations of ages involving radiogenic Pb^{207}.

TABLE 12

RESULTS OF ACID WASHING EXPERIMENTS ON MONAZITES

Locality	Fraction	Lead isotope ratio				Percentage of element in total sample which dissolved in cold 6M HCl		
		206/204	207/204	208/204	208/206	Uranium	Thorium	Lead
Quartz Creek, Colo.	Total sample	1010	92.9	6660	6.59			
	Acid soluble	82.3	18.4	185	2.25	5.2	2.8	1.7
Goodhouse, S. Africa	Total sample	530	50.2	6100	11.5			
	Acid soluble	189	26.7	1640	8.7	1.7	1.6	1.3
Houtenbek, S. Africa	Total sample	924	78.3	4610	4.99			
	Acid soluble	7000	526	1530	0.22	7.3	1.8	4.8
Steenkampskraal, S. Africa	Total sample	77.3	20.6	952	12.3			
	Acid soluble	44.5	16.7	410	9.2	..	..	..

minerals this year to Dr. J. Norton, Dr. D. A. Brobst, and J. A. Redden, of the U. S. Geological Survey; D. F. Hewitt, of the Ontario Department of Mines; and Dr. W. S. MacKenzie, of the Geophysical Laboratory.

THEORETICAL AND STATISTICAL GEOPHYSICS

Toroidal Magnetic Fields in the Ionosphere

S. E. Forbush and E. H. Vestine

It is usually assumed that the strongest electric currents in the ionosphere flow horizontally, since electric conductivity deduced by radio methods shows stratification in horizontal layers. Some linkage of current between layers should occur, yielding lines of magnetic force which may be mainly closed within the atmosphere. If such lines exist, observations at ground level are unlikely to disclose their presence; they are best detected by rocket techniques, but if large enough they should be observable by radio methods. Another possibility is that the more intense fields of this type, if present, may produce decreases in cosmic-ray intensity during magnetic storms.

As a first approach, reflected radio waves from the ionosphere near the 300-km level were examined during times when the cosmic-ray intensity decreased by 5 per cent or more during magnetic storms. The splitting of these waves in frequency near the F region of the ionosphere depends on the earth's magnetic field there. Unfortunately, the measured amount of splitting is affected by the distribution of irregularities in ionization in the F region, but in the case of the magnetic storm of July 25, 1946, in which cosmic rays decreased by 12 per cent, the largest decrease on record, a change of over 20 per cent in the earth's magnetic field was noted. This change, averaged over several hours, was about 0.12 oersted at Watheroo, Australia. Extension of this work to the results at other stations is currently under way, in order to examine whether or not the effect found was purely local.

Daytime Enhancement of the Initial Phase of Magnetic Storms at Huancayo

S. E. Forbush and E. H. Vestine

The sudden commencements (SC's) and initial phases (IP's) of magnetic storms tentatively described in last year's report as abnormally large at Huancayo, Peru, were subjected to statistical tests. From 428 SC's the frequency of occurrence was found to be independent of the time of day. The tests indicated that the average size of both SC's and IP's is significantly greater during the daylight hours at Huancayo. It was also established that the sizes of SC's and IP's there depend critically and linearly on the amplitude of the solar daily magnetic variation on the day of storm, as if the electric driving forces were mutually dependent. The amplitude of the solar daily variation is ordinarily considered to depend mainly on electric conductivity and the normal upper-air winds and tides near or within the E region. Since the conductivity depends mainly on solar X-ray emission, this result is of high interest in connection with theories of magnetic storms.

It is of particular interest to note also that this result establishes the atmosphere as the major site of the electric currents yielding field changes at ground level near Huancayo, at the beginning of magnetic storms. Another noteworthy result was that this effect found at Huancayo does not occur at Honolulu or San Juan. If the field changes at the latter stations are attributed to a world-wide current system, these changes average only about one-half as large as those found at Huancayo after removal of the part associated directly with the quiet-day daily variation. This suggests that all major sources of field during

the first part of a storm may be atmospheric. One possibility being examined from theory and motions of the F region is that the electric currents in the atmosphere near Huancayo are driven by electrojets of polar regions.

Cosmic-Ray Investigations

S. E. Forbush

Cosmic-ray intensity variation with sunspot cycle. The discovery of the world-wide variation in cosmic-ray intensity negatively correlated with sunspot numbers was described in last year's report. Since magnetic storms are often accompanied by decreases in cosmic-ray intensity, and since the frequency of magnetic storms increases with sunspot activity, a sunspot variation in cosmic-ray intensity with minimum near sunspot maximum would be anticipated. It has since been shown, however, that although the annual means of cosmic-ray intensity are always less for magnetically disturbed days (five per month) than for magnetically quiet days (five per month), the sunspot variation in cosmic-ray intensity is about the same for magnetically quiet as for magnetically disturbed days. Thus, the sunspot variation in cosmic-ray intensity is not due to magnetic-storm effects.

At all the cosmic-ray stations, except possibly Huancayo, there are systematic seasonal variations in cosmic-ray intensity due to the seasonal variation in the height of the 100-mb pressure level, where most of the μ-mesons are created. An increase in the height of the 100-mb level thus results in the decay of more μ-mesons into electrons and neutrinos, and since the electrons cannot penetrate the atmosphere and the lead shielding of the instruments, a decrease in ionization results. Thus, a sunspot variation in the height of the 100-mb pressure level could produce a sunspot variation in cosmic-ray intensity. Consequently, the U. S. Weather Bureau data from radiosondes, at Washington, were analyzed for the 10-year period 1944–1953. The average amplitude of the seasonal variation in the height of the 100-mb pressure level was found to be about 260 m. For the same years the amplitude of the seasonal wave in cosmic-ray intensity at Cheltenham was about 1.45 per cent, with phase opposite to that in the height of the 100-mb level. As calculated from the amplitudes of the two seasonal variations, an increase of 100 m in the height of the 100-mb level results in a decrease of 0.56 per cent in the apparent cosmic-ray intensity. Thus, a variation with sunspot cycle with amplitude about 300 m in the height of the 100-mb level would result in the observed variation in cosmic-ray intensity. However, the range in annual means of the height of the 100-mb level was only 75 m during the period 1944–1953, and no significant variation with sunspot cycle was evident. Thus, it is quite certain that the sunspot variation in cosmic-ray intensity is not due to meteorological effects.

Solar flare effect near geomagnetic pole. Since 1936, when the program of continuous operation of Compton-Bennett cosmic-ray ionization chambers was begun, four large increases of cosmic-ray intensity have begun within an hour after the onset of a solar flare (bright chromospheric eruption) or of a radio fadeout, which indicates a solar flare. These increases were attributed to charged particles from the sun. The geographical distribution of "impact zones" was calculated by Schlüter in Germany and by Firor at Chicago (now on the staff of this Department) for particles originating in the neighborhood of the sun. Though the impact zones are compatible with the meager observations available, the calculations indicate that no increase in cosmic-ray intensity should be observed within 30 degrees of latitude from either geomagnetic pole. Thus, the increases in cosmic-ray intensity observed at Godhavn, geomagnetic latitude 80° N, during all four flares, and by Rose at Resolute, geomagnetic latitude 83° N, during

the flare of November 19, 1946, are not explained by the present theory.

During the flare of July 25, 1946, a Carnegie Institution Millikan-Neher cosmic-ray electroscope was being operated aboard ship at Thule, Greenland, geomagnetic latitude 88° N, by J. W. Graham (now on the staff of this Department) while he was serving as observer for the Applied Physics Laboratory, Johns Hopkins University, on the Navy's arctic operation Nanook. Through the co-operation of the Applied Physics Laboratory, the records from this meter were recently made available for analysis. The results indicated that the cosmic-ray increase observed with the Millikan-Neher meter at Thule agreed as well with that observed with the Compton-Bennett meter at Godhavn as if both meters had been at the same place. This result emphasizes the fact that if the increase in cosmic-ray intensity is due to charged particles from the sun, then their arrival so near the geomagnetic pole requires explanation.

World-wide secular change in phase of the diurnal variation in cosmic-ray intensity. The yearly averages of the 24-hour solar wave in cosmic-ray intensity are found to show a large systematic variation in local time of maximum which is remarkably similar at Cheltenham (Maryland, U. S.), Huancayo (Peru), and Christchurch (New Zealand), although the local time of maximum at Huancayo is in all years about 3 hours earlier than that at Cheltenham and Christchurch. The reality of the effect is shown by statistical tests which definitely indicate that the variability (two-dimensional variance) of yearly averages of the 24-hour wave at Cheltenham or Christchurch is significantly greater than the variability of the differences between the yearly mean 24-hour waves at Cheltenham and Christchurch. From 1947 to 1954 the local time of maximum at Cheltenham, Christchurch, and Huancayo became progressively earlier by about 9 hours. The variation in phase appears unrelated to solar activity, and further observations will be needed to determine whether it is periodic.

Old cosmic-ray program. Compton-Bennett meters were satisfactorily operated throughout the report year at Godhavn (Greenland), Cheltenham (Maryland, U. S.), Climax (Alaska, U. S.), Ciudad Universitaria (Mexico, D. F.), Huancayo (Peru), and Christchurch (New Zealand). Tabulations of bihourly means of ionization corrected for bursts and barometric pressure for Huancayo are ready for publication from 1946 to 1954, and for Cheltenham from 1937 to 1954, as well as summaries for Godhavn and Christchurch. Publication of these results together with those contained in CIW Publication 175 will make available to investigators most of the essential data obtained since the start of the Department's cosmic-ray program.

Large ionization chamber. The large cosmic-ray ionization chamber was maintained in essentially continuous operation at Derwood during the report year. No large or small solar-flare effects were observed. If means can be found to reduce the time required to scale these records (10 scalings per hour), the results will be useful for investigating the 27-day recurrence tendency in diurnal variation.

Co-operation in operation of cosmic-ray meters. The successful operation of Compton-Bennett cosmic-ray meters over a long period at so many stations has been possible only through the wholehearted and unselfish co-operation of several organizations and individuals. We wish to express our appreciation to the following organizations for the operation and maintenance of cosmic-ray meters: the Danish Meteorological Institute and the staff of its Godhavn Magnetic Observatory at Godhavn, Greenland; the U. S. Coast and Geodetic Survey and the staff of its magnetic observatory at Cheltenham, Maryland; the High Altitude Observatory of Harvard University and the University of Colorado and its staff at Climax, Colorado; the Instituto Nacional de la Investigación Científica and

the Universidad de Mexico, Mexico, D. F.; the Government of Peru and the staff of its Instituto Geofísico de Huancayo; and the Department of Scientific and Industrial Research and the staff of its magnetic observatory at Christchurch, New Zealand.

LABORATORY PHYSICS

NUCLEAR PHYSICS

N. P. Heydenburg and G. M. Temmer

Coulomb Excitation Studies

For the past year we have continued our investigation of nuclear energy levels by the method of Coulomb excitation with alpha particles. During the summer of 1954 we spent three weeks at the Institute for Theoretical Physics in Copenhagen, Denmark, where we had fruitful and stimulating discussions with A. Bohr, B. R. Mottelson, and T. Huus concerning the unified (collective) model of the nucleus. As was mentioned in last year's report, the unified model of the nucleus, proposed by Bohr and Mottelson, predicts that nuclei removed from the region of the closed shells should exhibit a low-lying structure having a definite, simple spin sequence and level spacing. Our preliminary experimental results had confirmed their predictions rather well. During our discussions the need for more precise data on the transition probabilities for the observed gamma-ray transitions was emphasized.

Near the end of May 1954 we began using the weak beam of doubly charged helium ions having about twice the energy of the machine, i.e., up to 7 Mev, for our Coulomb excitation work. From tests made on resonance reactions with the singly and doubly ionized helium beams, where they could be made to overlap in energy, it became apparent that the doubly ionized beam did not originate in the ion source. It was produced at some distance from the ion source as a result of stripping of the second electron of He^+ in the residual tube gas. To take advantage of this phenomenon, we then inserted a stripping canal in the path of the beam about one-ninth of the tube length away from the source. Oxygen gas is admitted at the mid point of this canal, giving enough pressure to considerably enhance the stripping process. This gives an increase of a factor of 10 in the available doubly charged helium beam with currents up to 0.1 microampere.

Since the cross section for Coulomb excitation is a steeply rising function of the alpha-particle energy, our enhanced 6-Mev beam proved to be very advantageous, particularly for exciting some of the higher-energy transitions. After improving the reproducibility of our geometrical arrangement of target and gamma-ray counter, we embarked on a program of re-examining most of the gamma rays we had previously observed. Our aim was to obtain quantitatively reliable energies and intensities from which we could deduce energy-level transition probabilities. To this end we calibrated our geometry and crystal-counter efficiency with a calibrated radioactive gold-198 source from the National Bureau of Standards, which has a gamma ray at 411 kev.

We began by making a more complete study of the rare-earth nuclei. Our results on these nuclei were reported in some detail in last year's report. We found a number of additional examples of rotational levels having energies agreeing remarkably well with the predictions of Bohr and Mottelson. It should be recalled that the latter predict a series of levels, for deformed nuclei far removed from closed shells, having energies given by:

$$E_I = \frac{\hbar^2}{2\mathfrak{J}} I(I+1) \qquad (1)$$

where I is the spin of the level and $\mathfrak{J}$ is the effective moment of inertia of the nucleus (only that part associated with the deformation from sphericity). For nuclei with even charge and mass numbers, I

will successively take on the values 0, 2, 4, 6, ... For odd-mass nuclei I will take values I_0, I_0+1, I_0+2, . . . , where I_0 is the spin of the ground state. Since only electric quadrupole ($E2$) transitions are effectively induced in the Coulomb excitation process, and these require a vectorial spin difference $\Delta I=2$, we should excite the $I=2$ level in even-even nuclei and both the I_0+1 and I_0+2 levels in odd-A nuclei. Seven odd-A nuclei were reported last year as having this type of level scheme. This year Hf^{177}, Hf^{179}, Tb^{165}, and Tm^{169} have been added to the list. A summary of our results is given in table 13.

A number of first-excited state $0\rightarrow2$ transitions in even-even nuclei were also observed, most of them being identified by the use of enriched isotopes from Oak Ridge National Laboratory. The systematics of these 2^+ levels is illustrated in figure 4, where the level energy is plotted as a function of neutron number N. Near a closed shell, nuclei are expected to be less deformed, hence $\mathfrak{I}$ in equation (1) will be smaller and E_I should become larger. This trend can be seen as N decreases toward the closed shell at $N=82$.

Table 14 summarizes our results for the rare-earth region. The values for the reduced transition probability $\varepsilon B(E2)$ have been calculated from observed gamma-ray intensities by a method discussed in detail elsewhere. Values of the intrinsic electric-quadrupole moment Q_0 can be calculated from $\varepsilon B(E2)$ values. From table 14, the expected trend to smaller values of $\varepsilon B(E2)$ near the closed shell can also be discerned. The lowest energy transitions are enhanced relatively to the higher energy transitions when internal conversion coefficients are taken into account.

TABLE 13

SUMMARY OF RESULTS ON ROTATIONAL LEVEL POSITIONS IN ODD-A NUCLEI OF THE RARE-EARTH REGION

Only nuclei having "conventional spectra" are listed ($I_0>1/2$). ρ_{exp} stands for experimental ratio of second- to first-excited state energies; ρ_{theor} is obtained from equation (1). Values of ground-state spin I_0 in parentheses are assumed.

Nucleus	I_0	E_{I_0+1} (kev)	E_{I_0+2} (kev)	ρ_{exp}	ρ_{theor}
$_{63}Eu^{153}$	5/2	82	187	2.28±0.04	2.29
$_{65}Tb^{159}$	3/2	57 *	136	2.39±0.05	2.40
$_{66}Dy^{161,\,163}$ †	(7/2)	76	166 †	2.18±0.04	2.22
$_{67}Ho^{165}$	7/2	94	206	2.19±0.04	2.22
$_{68}Er^{167}$ †	7/2	79	172 †	2.18±0.04	2.22
$_{70}Yb^{173}$ †	5/2	78	180 †	2.31±0.04	2.29
$_{71}Lu^{175}$	7/2	114	250	2.19±0.04	2.22
$_{72}Hf^{177}$	(7/2)	112	250	2.23±0.04	2.22
$_{72}Hf^{179}$	(7/2)	119	260	2.18±0.04	2.22
$_{73}Ta^{181}$	7/2	136	303	2.23±0.04	2.22

* Inferred from 79-kev cascade radiation; conversion electrons directly observed by T. Huus.
† Conclusions, based on systematics, are tentative.

From preliminary observations of Coulomb-excited gamma rays from elements below $Z\sim60$ with 6-Mev alpha particles, it was evident that we would be able to measure the energies and transition probabilities of the first-excited states of a considerable number of even-even nuclei in the medium-heavy elements. The identification of the isotope responsible for an observed gamma ray is in general not possible unless the level is already known from beta-ray spectroscopy. Hence most of our work with these elements has been done with enriched isotopes. Molybdenum and germanium isotopes were obtained

from Oak Ridge National Laboratory. In addition to these, enriched isotopes of nearly all the selenium, palladium, and cadmium isotopes were obtained on a temporary secondary loan from Brookhaven National Laboratory through the kindness of Mrs. Scharff-Goldhaber. The striking effect is in part due to the nature of the Coulomb excitation process and to counter efficiency. Figure 6 shows a plot of the first-excited state energies as a function of the neutron number. Here it is seen that the first-excited state energy increases systematically near the closed neutron shell

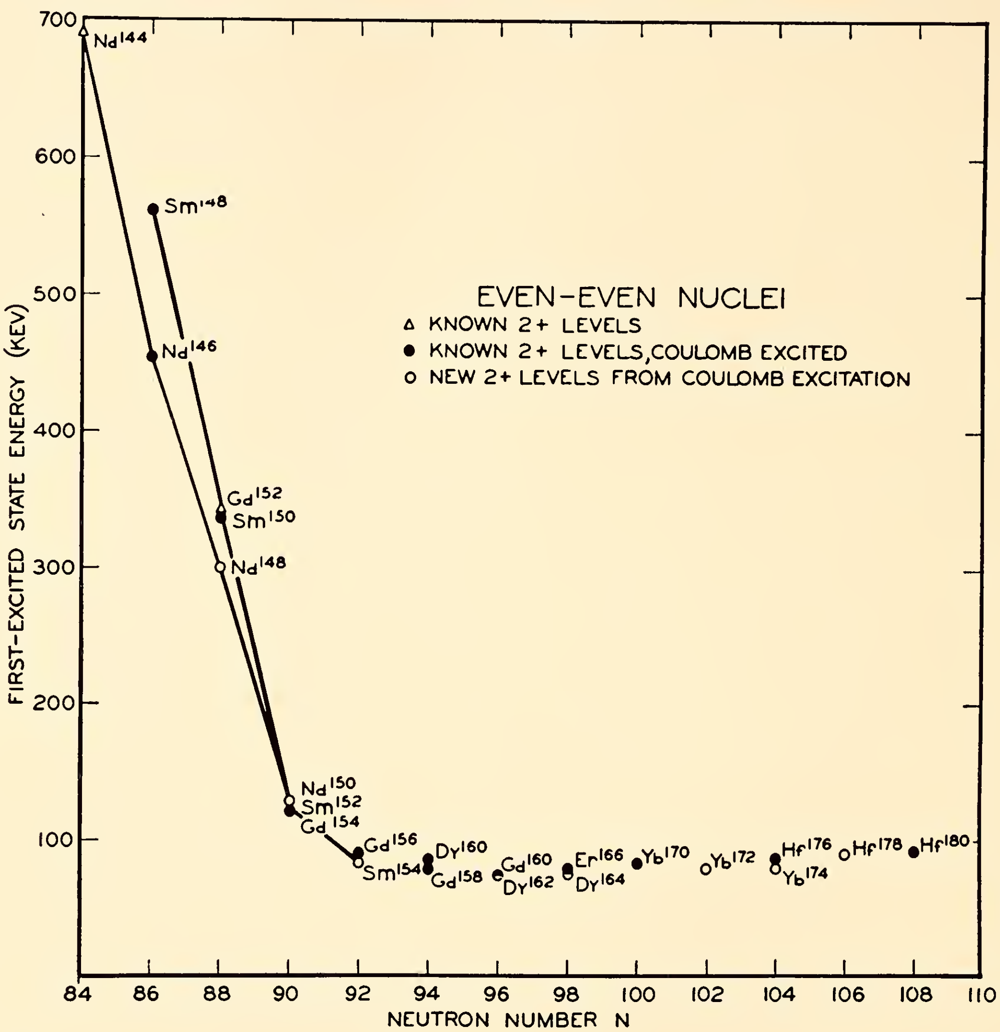

FIG. 4. Summary of results on even-even rare-earth nuclei. Energies of first-excited (2^+) states vs. neutron number. Δ, known states, not Coulomb-excited; ●, known states, Coulomb-excited; O, new states discovered by Coulomb excitation. Levels for elements where no enriched isotopes are available (Dy, Er, Yb) are shown at an average position.

way in which the first-excited states unfold from a study of Coulomb-excited gamma rays from enriched isotopes is illustrated in figure 5. This is a composite graph showing the scintillation pulse-height distributions of gamma rays from four of the even-*A* isotopes of palladium. It can be seen that the energy of the gamma ray increases with decreasing mass number *A* of the isotope, while the intensity of the gamma ray decreases. The latter intensity at $N=50$. Another valley is evident for values of N below 50. We have found the first-excited state for ten nuclei in this region which were not previously known. For several of these nuclei it would be impossible to excite the states in any other way, because the neighboring nuclei are either stable or unknown, or if radioactive do not decay in the proper way to excite the transition of interest.

A summary of gamma-ray transitions

we have observed between $Z=22$ and $Z=48$ is given in table 15. Values for the reduced transition probabilities, $\varepsilon B(E2)$, and equivalent lifetimes have been calculated for these transitions. In general, these note. It is the only case where we have observed delayed gamma radiation from an isomeric state. Two transitions are directly Coulomb-excited, one at 244 kev and the other at 457 kev. The isomeric state

TABLE 14

SUMMARY OF RESULTS ON COULOMB EXCITATION OF RARE-EARTH NUCLEI BY 6-MEV ALPHA PARTICLES

Entries in parentheses are tentative assignments

Element	A	I_0	E_γ (kev)	$\epsilon B(E2)$ (10^{-48} cm^4)
$_{60}$Nd	145	7/2	70	~0.03 *
	146	0^+	455	0.84
	148	0^+	300	1.50 *
	150	0^+	128	1.24 *
$_{62}$Sm	148	0^+	562	2.06
	150	0^+	337	2.32 *
	152	0^+	122	1.36
	154	0^+	82	0.48
$_{63}$Eu	(151)	5/2	310	0.64
	153	5/2	82	0.36
			105 †	0.15 †
			187	0.49
$_{64}$Gd	154	0^+	123	2.10
	155	(7/2)	145	0.112 *
	156	0^+	89	1.24
	157	(7/2)	131	0.083 *
	158	0^+	79	1.02
	160	0^+	76	~1
$_{65}$Tb	159	3/2	136†	0.041†
$_{66}$Dy ‡	161	(7/2)		
	162	0^+		
	163	(7/2)	76	0.23 ‡
	164	0^+		
	(161)	(7/2)	166	0.29 ‡
	(163)	(7/2)		
$_{67}$Ho	165	7/2	94	0.54
			206	0.036
$_{68}$Er ‡	162	0^+		
	164	0^+		
	166	0^+		
	167	7/2	79	0.48 ‡
	168	0^+		
	170	0^+		
	(167)	7/2	172	0.081 ‡
$_{69}$Tm	169	1/2	109 †	1.12 †
$_{70}$Yb ‡	170	0^+		
	172	0^+		
	173	5/2	78	0.28‡
	174	0^+		
	176	0^+		
	(171)	1/2	110	0.20 ‡
	(173)	5/2	180	0.086 ‡
$_{71}$Lu	175	7/2	114	0.72
			250	0.20
	(176)	>9	180	(1.14)
$_{72}$Hf	176	0^+	87	0.56 *
	177	?	112	0.77 *
			250	0.55 *
	178	0^+	90	0.85
	179	?	119	0.67 *
			260	0.056 *
	180	0^+	93	0.78 *
$_{73}$Ta§	181	7/2	136	0.70
			167†	~0.13†
			303	0.15

* Isotopically enriched target used; all other assignments from natural targets.
† Cascade radiation from second rotational state, whose ΔE is used in computing ξ_0.
‡ Preliminary assignments until enriched isotopes become available.
§ Metallic target; all others are oxides of the form X_2O_3 (except HfO_2).

lifetimes are too short to be measured by other methods now known. The transition probabilities are 10 to 20 times stronger than for single-particle $E2$ transitions and confirm the collective (i.e., many-particle) nature of the transitions.

The nucleus Se^{77} is worthy of special at 160 kev is known to have a half life of 17.5 seconds and a spin $I=7/2$. This cannot be excited directly by an $E2$ excitation process from $I_0=1/2$, since $\Delta I=3$. We have evidence, from the similarity in shape of the excitation curves of the 244-kev and 160-kev gamma rays as a function of alpha

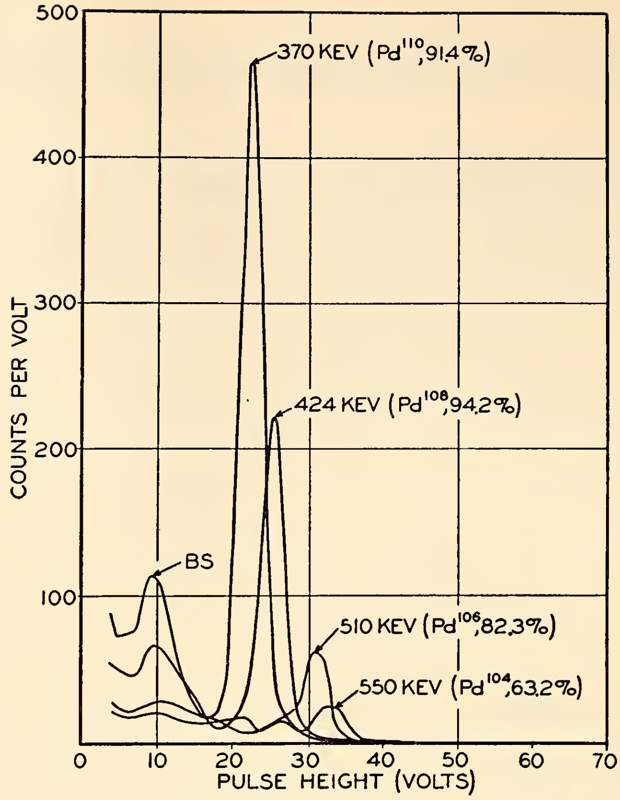

FIG. 5. Pulse-height spectra obtained for gamma rays from enriched even-even palladium isotopes under 6-Mev alpha-particle bombardment. 1¾″ × 2″ NaI crystal. Gamma-ray energies, isotopes responsible, and target enrichments are indicated over each peak. Peak *BS* is due to back-scattered gamma rays.

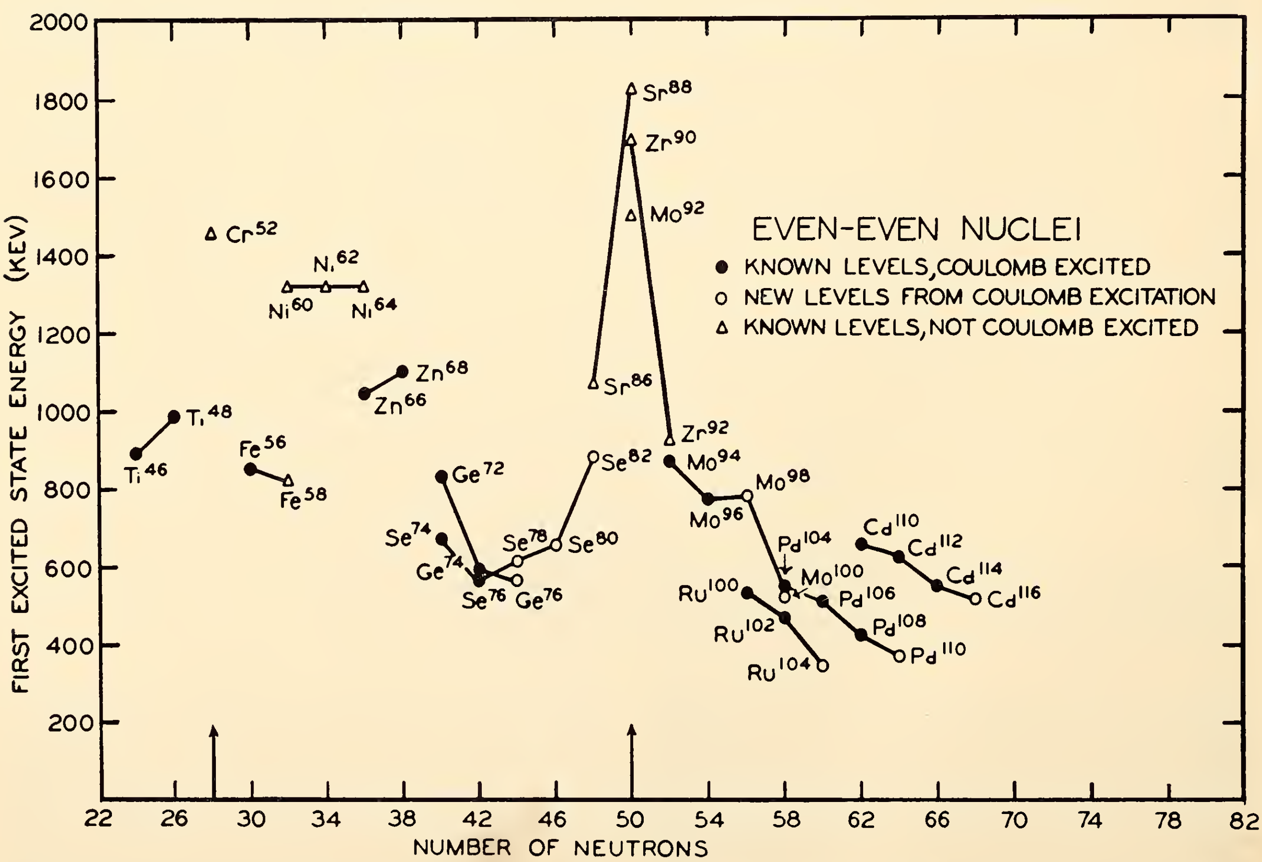

FIG. 6. Summary of results on even-even nuclei $Z = 22$ to $Z = 48$. Energies of first-excited (2^+) states vs. neutron number. Δ, known states, not Coulomb-excited; ●, known states, Coulomb-excited; ○, new states discovered by Coulomb excitation. Vertical arrows mark closed neutron shells.

TABLE 15

SUMMARY OF RESULTS ON COULOMB EXCITATION OF NUCLEI ($Z = 22$ TO $Z = 48$) BY 6-MEV ALPHA PARTICLES

Entries in parentheses are tentative assignments. I_0, ground-state spin; I^*, excited-state spin; $\varepsilon B(E2)$, experimental reduced quadrupole transition probability (see text); Q_0, intrinsic quadrupole moment calculated from $\varepsilon B(E2)$; $\tau_\gamma(E2)$, equivalent radiative lifetime for decay

Element	A	E_γ (kev)	$I_0 - I^*$	$\epsilon B(E2)$ (10^{-48} cm^4)	Q_0 (barns)	$\tau_\gamma(E2)$ (sec)
$_{22}$Ti	46	890	$0^+ - 2^+$	0.28	1.7	2.6×10^{-12}
	48	990	$0^+ - 2^+$	0.20	1.4	2.1×10^{-12}
$_{26}$Fe	56	854	$0^+ - 2^+$	0.21	1.5	4.2×10^{-12}
$_{29}$Cu	63	690 †	$3/2 - ?$	0.017	...	....
		990	$3/2 - ?$	0.069	...	$6.3 - 19 \times 10^{-13}$
$_{30}$Zn	64	1000	$0^+ - 2^+$	0.27	1.6	1.5×10^{-12}
	66	1040	$0^+ - 2^+$	0.22	1.5	1.6×10^{-12}
$_{32}$Ge	70	1020 †	$0^+ - 2^+$	0.19	1.4	2.0×10^{-12}
	72	830	$0^+ - 2^+$	0.53	2.3	1.9×10^{-12}
	74	593	$0^+ - 2^+$	0.43	2.1	1.3×10^{-11}
	76	566 †	$0^+ - 2^+$	0.46	2.1	1.5×10^{-11}
$_{33}$As	75	200	$3/2 - ?$	0.012	...	....
		283	$3/2 - ?$	0.049	...	....
		574 †	$3/2 - ?$	0.10	...	....
		814 †	$3/2 - ?$	0.13	...	....
$_{34}$Se	74	635	$0^+ - 2^+$	0.32	1.8	1.2×10^{-11}
	76	567	$0^+ - 2^+$	0.60	2.5	1.2×10^{-11}
	77	244	$1/2 - (3^-/2)$	0.12	...	1.5×10^{-9}
		457 †	$1/2 - (5^-/2)$	0.33	...	3.7×10^{-11}
	78	615 †	$0^+ - 2^+$	0.54	2.3	8.6×10^{-12}
	80	654 †	$0^+ - 2^+$	0.37	1.9	9.3×10^{-12}
	82	880 †	$0^+ - 2^+$	0.12	1.1	6.2×10^{-12}
$_{42}$Mo	94	871	$0^+ - 2^+$	0.61	2.5	1.3×10^{-12}
	95	204	$5^+/2 - 3^+/2$	0.035	...	4.5×10^{-9}
	96	778	$0^+ - 2^+$	0.59	2.4	2.4×10^{-12}
	98	786 †	$0^+ - 2^+$	0.52	2.3	2.6×10^{-12}
	100	528 †	$0^+ - 2^+$	0.85	2.9	12×10^{-12}
$_{44}$Ru	99	89.5 †	$5/2^+ - (1/2^+, 3/2^+)$	0.020	...	4.7×10^{-7}
	100	540	$0^+ - 2^+$	0.39	2.0	2.3×10^{-11}
	101	127 †	$5/2^+ - (9/2^+)$	0.021	...	2.0×10^{-7}
	102	473	$0^+ - 2^+$	0.74	2.7	2.3×10^{-11}
	104	362	$0^+ - 2^+$	0.90	3.0	8×10^{-11}
$_{46}$Pd	104	550	$0^+ - 2^+$	0.61	2.5	1.3×10^{-11}
	105	266	$5/2 - ?$	0.013	...	....
		433	$5/2 - ?$	0.18	...	....
	106	510	$0^+ - 2^+$	0.73	2.7	1.6×10^{-11}
	108	424	$0^+ - 2^+$	0.80	2.8	3.9×10^{-11}
	110	370	$0^+ - 2^+$	0.94	3.1	6.3×10^{-11}
$_{48}$Cd	110	654	$0^+ - 2^+$	0.66	2.6	5.2×10^{-12}
	111	340	$1/2 - 3/2$	0.16	...	2.3×10^{-10}
	112	620	$0^+ - 2^+$	0.70	2.6	6.4×10^{-12}
	113	290	$1/2 - (5/2)$	0.08	...	1.5×10^{-9}
		550?		< 0.27	...	....
	114	550	$0^+ - 2^+$	0.73	2.7	1.1×10^{-11}
	116	508	$0^+ - 2^+$	0.76	2.8	1.6×10^{-11}

† New level.

energy, that we are exciting the 160-kev gamma by an 84-kev cascade transition from the 244-kev to the 160-kev level. The intensity of the delayed 160-kev transition was sufficient to enable us to identify it by its half life. The decay curve is shown in figure 7.

In addition, a gamma ray of 211 kev was shown to be in coincidence with some of the 244-kev radiation, so that we propose the decay scheme shown in figure 7. Angular distribution measurements were used to assign the spins of the excited states. The

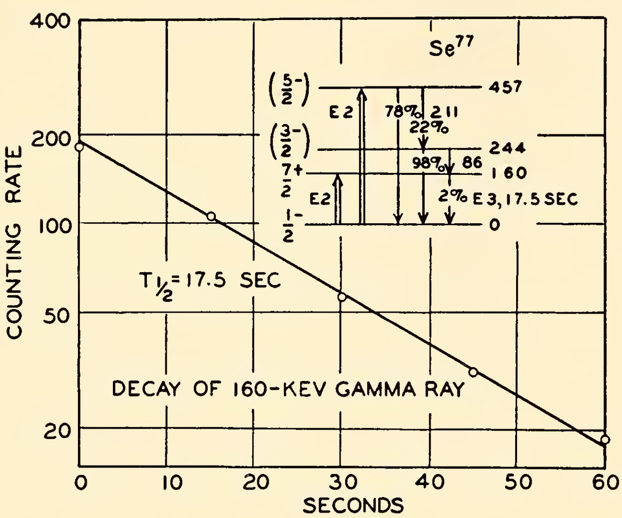

FIG. 7. Decay curve of 160-kev isomeric transition in Se^{77}. Insert shows proposed decay scheme for Se^{77}; double arrows indicate Coulomb excitation; short upward arrow on left should extend to 244-kev level.

level at 457 kev (and hence its 211-kev cascade) is not observed in the radioactive decay of either neighbor of Se^{77} (As^{77} and Br^{77}).

Nuclear Alignment

In continuation of the low-temperature nuclear alignment experiments (discussed in some detail in the last report) carried out by Temmer in collaboration with Ambler and Hudson at the National Bureau of Standards, one additional radioactive nucleus, Ce^{139}, was incorporated into the same crystal that was previously used. A sizable anisotropy was observed in the emission pattern of the 166-kev gamma ray emitted from the first excited state of La^{139}, leading to the assignment of magnetic dipole character to this transition, with some admixture of electric quadrupole radiation. It turns out that the anisotropy is very sensitive even to slight admixtures of this kind because of interference effects, which were known to exist from gamma-gamma angular correlation experiments, and depend on the magnitude and phase of the relative amplitudes rather than intensities of the competing radiations. Larger anisotropies than are obtained with pure radiation of either kind may arise, and have been observed in the case of Ce^{139}.

Cyclotron

Throughout the year the cyclotron has been operated every other month on the average, mainly for the preparation of radioactive species for our own use, and for that of several investigators from local institutions. R. W. Hayward (National Bureau of Standards) has studied the decay schemes of Nb^{91}, Nb^{92}, and Se^{73}, as well as the internal *Bremsstrahlung* accompanying the pure K-capture decay of a sample of V^{49} which we prepared some time ago to clear up existing discrepancies in isotope assignments. C. L. McGinnis (National Research Council) has studied the decay of Pd^{111}, In^{117}, and Sb^{117}, which yields information about the level structure of Sn^{117} and Sb^{120}. R. van Lieshout (National Research Council) has used our facilities for the preparation of Sc^{43}. External beams of both deuterons (up to 20 microamperes at 16 Mev) and alpha particles (about 0.5 microampere at 32 Mev) were used for these bombardments.

For future utilization of our external cyclotron beam, we have decided to make two magnetic focusing lenses of the quadrupole type, following a design evolved at the University of Rochester. These magnets are now in production. We have had the assistance of J. Z. Klose (U. S. Naval Academy) in the design calculations.

BIOPHYSICS

E. T. Bolton, R. J. Britten, D. B. Cowie, and R. B. Roberts

During the past year the biophysics section, a small group of physicists who have undertaken the study of order and process in living materials, has made a major shift in its objectives. Previously we were content to study ways in which cells synthesize small molecules for subsequent incorporation into macromolecules. This year we have attempted to learn something of the processes by which the small-molecule building blocks are assembled to make the biologically active molecules of protein and nucleic acid. We were persuaded to make this shift not so much because the study of small molecules was complete, as because the new field offered a greater challenge together with some hope that significant progress was possible.

During the past few years several promising models for the synthesis of macromolecules have been put forward. The Watson-Crick structure for deoxyribose nucleic acid (DNA) provides a model of a molecule which is inherently capable of being precisely duplicated. It consists of two spiral chains, each of which carries the same information. Consequently, if it is split into two halves, each half has the capacity for accumulating the missing material and being reconstituted into the original form.

This model is particularly useful in the attempt to understand how certain virus particles are reproduced and how genes are duplicated and transmitted down through the generations with few changes. It is less useful, however, in giving any clear picture of synthesis of the other biologically important macromolecules, ribose nucleic acid (RNA) and protein. Somehow the DNA molecule must have an influence in determining what types of RNA and protein molecules are synthesized, or it would have no genetic significance. Furthermore, RNA must have some of the same properties, since RNA seems to be the active ingredient of many plant viruses. Finally, specific proteins must be synthesized; possibly RNA acts as a template for arranging the order of amino acids in a peptide chain.

Certain specific questions can be asked which have a bearing on these general ideas. Are amino acids utilized as such, or are they first linked into small peptides? If a template is involved in protein synthesis, can the adsorption of amino acids on the template be observed? If so, can the nature of the template molecule and the type of binding be determined? Experiments which answered these questions would clarify many of the fuzzy areas of macromolecule synthesis.

During the year we have studied the kinetics of protein formation in bacteria and yeast. Specific adsorption of amino acids as a first step in their incorporation into proteins has been observed. In the coming years, further studies of the adsorbed amino acids may reveal the nature of the templates used by the cell for protein synthesis.

Incorporation of Amino Acids into Protein

Escherichia coli. E. coli will utilize amino acids added to the culture fluid. It is possible to prepare these amino acids with such a high specific radioactivity (25 per cent C^{14}) that 0.01 microgram can be measured with ease. These compounds thus provide a "chemical microscope" which focuses on a very small part of the total material being used by the cell and ignores the rest. If, for example, 0.008 micromole of C^{14} proline is added to a 20-ml culture containing 4 mg (dry weight) of growing bacteria, ten successive samples can be taken to measure the incorporation of the proline and its synthesis into protein. In this particular case it has been found that the entire quantity of proline added is used by the cells and incorporated into protein in less than a minute. Consequently, special techniques have been

necessary to take samples rapidly enough to observe the time course of these events. The radioactive material is injected violently into the culture of bacteria to provide rapid mixing. Samples are then taken and squirted either into trichloracetic acid (TCA) to stop the biochemical reaction, or onto a suction filter which separates the bacteria from their culture fluid in less than five seconds.

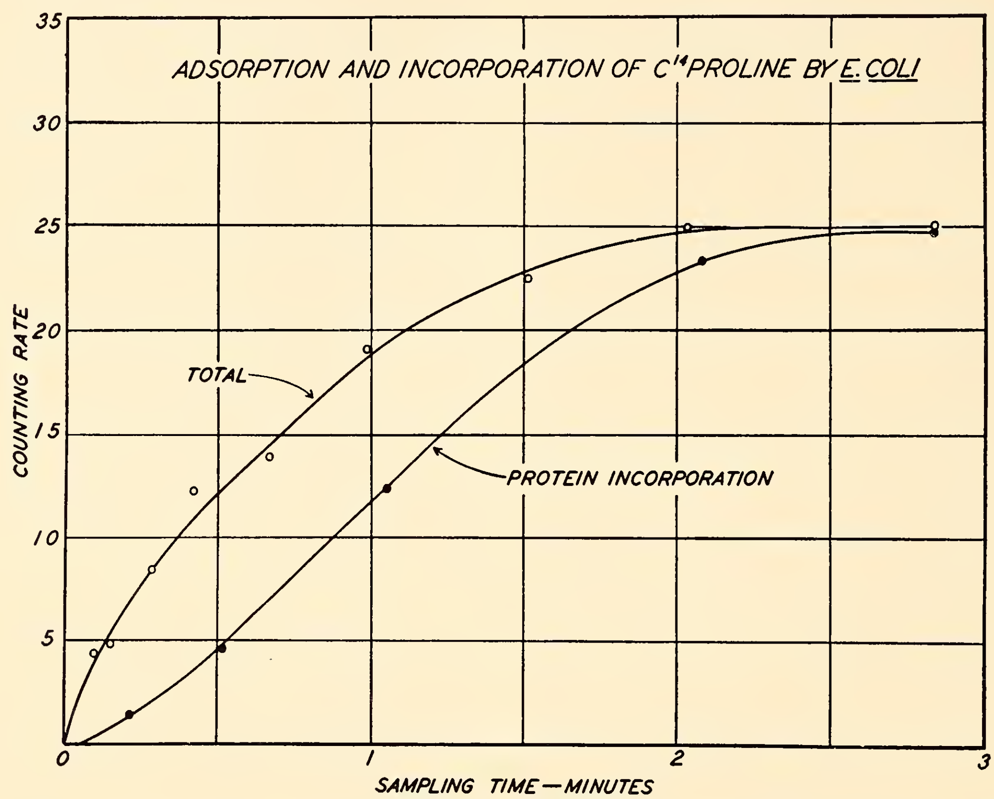

FIG. 8. Adsorption and incorporation of C^{14} proline by growing *Escherichia coli.* The suspension contained mineral salts, ammonia, glucose, C^{14} proline at 0.38×10^{-6} molar, and 0.08 mg (dry weight) cells per ml.

A typical curve obtained in this fashion is shown in figure 8. The total radioactivity derived from proline which is held in the cells is measured by the radioactivity caught on the filter. The quantity bound in large molecules is given by the radioactivity which is not extractable by TCA, and the difference shows the quantity in the TCA-soluble fraction. Paper chromatograms of the TCA-soluble fraction show proline as the only radioactive compound among the many different small molecules which appear in this fraction. Chromatograms and other chemical tests show that the radioactivity which is not extracted by TCA is firmly bound into high-molecular-weight compounds and is released as proline by acid hydrolysis.

In this experiment the quantity of proline in the TCA-soluble fraction 20 seconds after the proline was added was 280 μM per ml volume of cells, whereas the original concentration in the cells was too small to be detected and that in the medium itself was only 0.38 μM per ml. This accumulation shows that the proline is bound in a nondiffusible form, probably by adsorption to some larger molecule of the cell.

Furthermore, the adsorbed proline of the soluble fraction is so rapidly converted to protein that after 120 seconds all the proline is bound into protein. Clearly the adsorbed amino acid is readily available for protein synthesis.

This experiment, however, does not show that adsorption is a necessary step in protein synthesis. Two interpretations are

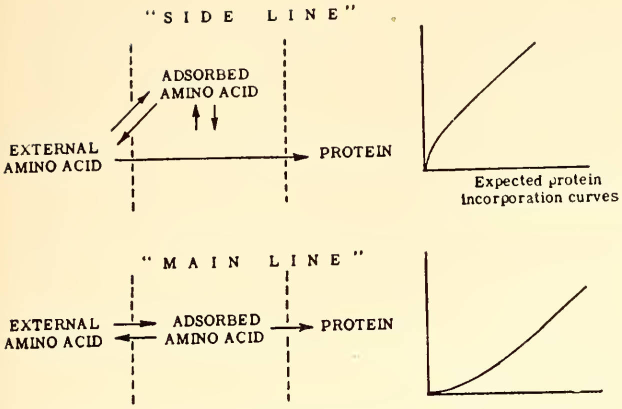

FIG. 9. Schematic illustration of two interpretations of the function of the adsorbed amino acid. At the right are shown the expected curves for incorporation of C^{14} proline into the protein when the cells have been pretreated with C^{12} proline.

shown in figure 9. To distinguish between these possibilities, the adsorption sites of the cells were first exposed to C^{12} proline, and C^{14} proline was added one minute later. If the adsorption sites served only as a storage mechanism (upper drawing), then it would be expected that the C^{14} proline would initially enter the protein at full specific radioactivity and later would be diluted with C^{12} proline as the C^{12} proline was released from storage. Instead, figure 10 shows that the C^{14} proline begins to enter the protein only as it replaces the previously adsorbed C^{12} proline. The rate of incorporation of C^{14} into protein is precisely proportional to the C^{14} content of the TCA-soluble fraction. Thus adsorption of proline is a necessary step in protein synthesis.

The adsorption process is highly specific. In a series of special experiments we found that the adsorption of proline is not appreciably influenced by the presence of 15 other amino acids, each at a concentration 100 times that of proline. Such a specificity is of course necessary at some stage of protein synthesis, to assemble the amino acids in the proper order.

The adsorption process appears to require energy. Figure 11 shows the course of adsorption and protein synthesis in cells lacking glucose. Adsorption and protein synthesis are both markedly increased by

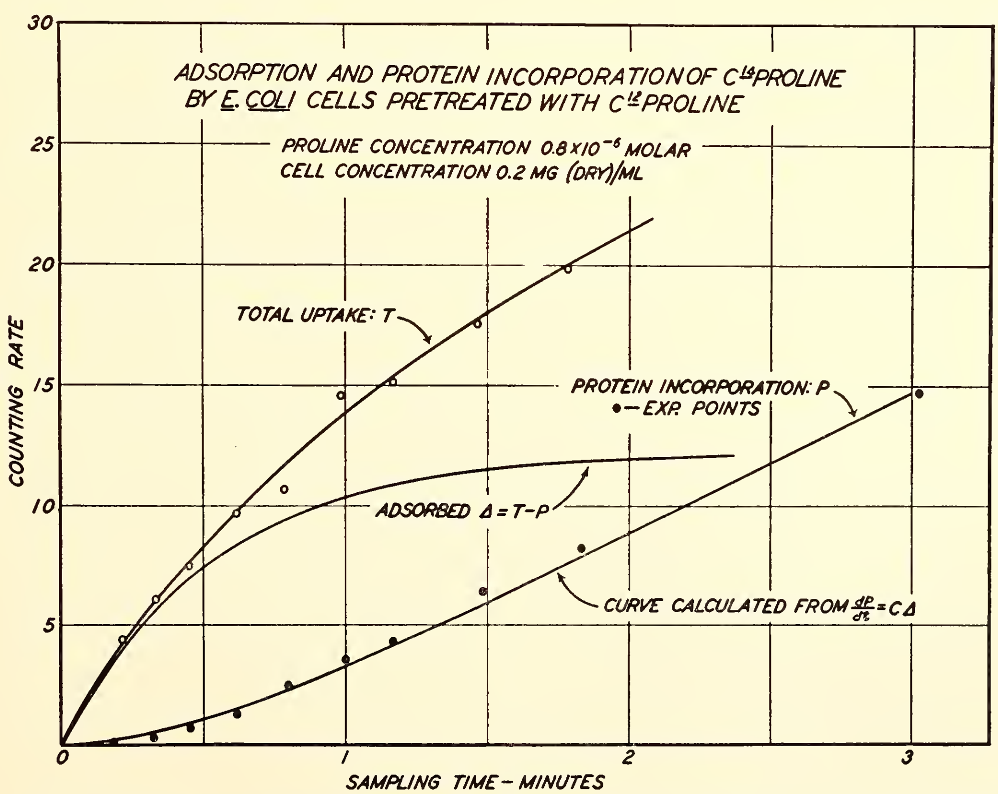

FIG. 10. C^{12} proline (0.8×10^{-6} molar) was added 1 minute before the carrier-free C^{14} proline. An amount of medium was added with C^{14} proline such that there was no change in proline concentration.

the addition of glucose. Inhibition of adsorption is also produced by the presence of dinitrophenol (10^{-3} M).

Adsorption without protein synthesis can be observed in several ways. A methionine-requiring mutant adsorbed proline (and converted an appreciable quantity to glutamic acid), but could not incorporate the proline into protein until methionine was added. Similarly, cells blocked by chloramphenicol cannot incorporate proline into protein, but can adsorb it readily. Cells held at 0° C do not adsorb proline or synthesize protein. If the sites are previously saturated by exposure to C^{12} proline at 24°, however, then C^{14} proline can exchange onto the adsorption sites at 0° C.

The bonds holding proline in the adsorbed state must be weak. Proline is readily extracted by cold TCA; the effects of this and other extracting agents are listed in table 16.

Most of the studies of adsorption have been carried out with proline. There are many advantages in using proline, as it is an end product of amino acid synthesis and it is not appreciably degraded. Methionine, which has similar properties, has been used to check all the major points observed with proline. The results have been entirely similar. We have also carried out a few experiments with alanine, valine, glutamic acid, phenylalanine, tyrosine, arginine, and lysine. In all cases the adsorption prior to incorporation into protein can be readily observed. With phenylalanine, tyrosine, arginine, and lysine a slight degree of adsorption was observed when glucose was lacking. Perhaps these chemically reactive amino acids also adsorb on other sites. In addition, the adsorption of a mixture of amino acids was observed by using a radioactive protein hydrolyzate. The general course of events was similar to that observed with proline and methionine.

From these observations of amino acid adsorption some facts emerge which di-

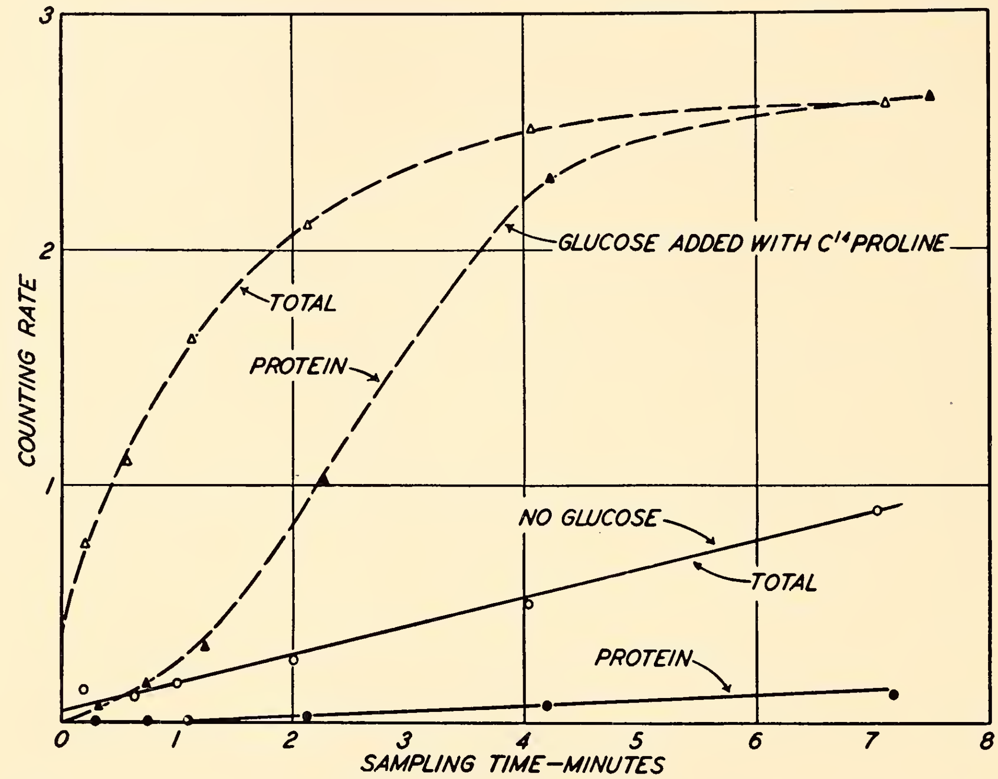

FIG. 11. Effect of glucose on the incorporation of C^{14} proline. Lower curves (solid lines) show the incorporation in the absence of glucose. Upper curves (dashed lines) show the incorporation when 0.1 per cent glucose was added with the C^{14} proline. C^{14} proline concentration, 0.28×10^{-6} molar; cell concentration, 0.07 mg (dry weight) per ml; temperature, 37° C.

rectly relate to the mechanisms of protein synthesis: (1) Adsorption appears to be a necessary first step in protein synthesis.

TABLE 16

Extraction of adsorbed proline

Added reagent	Final concentration	Percentage of TCA-soluble proline extracted
TCA	5%	100
TCA	0.25%	20
Ethanol	10%	0
Ethanol	20%	47
Ethanol	30%	95
Ethanol	40%	107
Butanol	10%	90
Toluene	saturated	20
Pyridine	1%	0
Roccal	0.5%	100
Dinitrophenol	0.002 M	40
Glucose	10%	0
NaCl	10%	35
NaOH	pH 10.5	116
NaOH	pH 8.1	40
NaOH	pH 7.7	10
HCl	pH 6.5	0
HCl	pH 5.5	26
HCl	pH 4.7	50
HCl	pH 4.3	60
HCl	pH 2.8	47
HCl	pH 1.8	101
HCl	pH 1.0	100
Chill to — 80° C and thaw:		
once		25
twice		37
Sonic disintegration to reduce optical density at 650 mμ by 70%		80

Samples of a suspension in exchange equilibrium were added to tubes at 0° C containing reagents in the proper amounts to bring the final suspension to the condition described in column 2. After 10 minutes these suspensions were filtered and the fraction of the TCA-soluble proline that had been extracted was calculated from the radioactivity of the precipitate.

(2) The adsorption is highly specific. (3) Energy is required for adsorption. (4) Peptide intermediates were not observed even though the conditions were highly favorable for finding them.

These observations can also be used to formulate a tentative model of protein synthesis which is useful in the design of further experiments. The specificity of the adsorption implies that a large molecule is involved. Furthermore, the amino acid does not leave the adsorption site before being bound into protein. Accordingly, it appears that the adsorbing molecule does act as the template for protein synthesis, and the specificity provides the mechanism for ordering the peptide chain. Also, the incorporation of proline into peptides was blocked in a mutant which lacked only a single amino acid. Therefore, it appears that all the amino acids must be adsorbed and in place on the template before the peptide chain begins to form. The formation of the peptide linkages might well proceed like a falling row of dominoes, with the formation of one peptide linkage initiating the formation of the next linkage along the chain.

RNA seems to be the most logical template molecule. It has long been known to be associated with protein synthesis, and there is plenty of it in these cells to provide binding sites. For example, if 5 per cent of the nucleotides were specific for adsorption of proline (proline is 5 mole per cent of the protein), then there should be 25 μM of sites available. The usual adsorption observed is only 3 to 5 μM, but it is quite possible that most of the sites are covered by peptide chains which are already formed but not yet disentangled from the RNA.

It seems likely that the energy required for adsorption has an important role in protein synthesis. If the amino acids were converted to an active form, perhaps phosphorylated, and received energy from a common source before being adsorbed, it would be expected that an excess of other amino acids would compete for the energy source and would thereby interfere with the adsorption of proline or methionine. Since we find that this does not occur, it seems reasonable to believe that the energy

is used to prepare the site for the subsequent adsorption of the amino acid. A part of the energy could remain in the amino acid–adsorption site complex to supply the energy required for the synthesis of the peptide bonds.

To summarize, these studies have already provided an experimental demonstration of two features which are necessary for any model of protein synthesis, namely, specificity and energy requirement. More important, perhaps, they have provided methods which may eventually show which molecule is acting as a template and what kind of bonding is involved.

Yeast. Studies of the yeastlike organism *Torulopsis utilis* have been carried on concurrently with the work on *E. coli*. The main effort has been directed toward understanding the flow of material from the medium through various pools of metabolic intermediates into the macromolecules of protein and nucleic acid. As a first step in these studies it was necessary to determine the composition of the various chemical fractions obtained from *T. utilis*. This is best done by growing cells from a small inoculum in the presence of tracers, so that the whole cell is uniformly labeled. Once the composition of the cells is known, it is possible to observe the transient effects of adding a tracer to a culture and observing the incorporation of the tracer first into the pools of metabolic intermediates and later into the end products. Also the losses of tracers from metabolic pools can be observed by suddenly removing or diluting the tracer material. In this way it is possible to single out the precursors of protein and nucleic acid. In these experiments it is essential to be sure that the cells are in a steady-state condition of exponential growth, otherwise the interpretation is confused by changing pool sizes.

Distribution of carbon and phosphorus among the chemical fractions of the cell. A first step in understanding the biosynthetic mechanisms in a growing microorganism is a knowledge of the distribution of the carbon and phosphorus among the chemical fractions of the cell. Figure 12 shows this distribution and demonstrates that steady-state conditions exist. The TCA-soluble fraction contains the "free amino acid pool," and consists of amino acids accounting for at least 90 per cent of the carbon of this fraction. Thirty per cent of the phosphorus of the cell is also contained in this fraction.

Hot alcohol extracts the "alcohol-soluble proteins" and the lipides of the cell, which together contain 10 per cent of the total carbon and phosphorus.

Hot TCA extracts almost all the remaining phosphorus and 27 per cent of the total carbon. The nucleotides do not account for all this phosphorus and carbon, since there is about twice as much phosphorus and 3.4 times as much carbon as is required for the cell's nucleic acid.

The TCA-precipitable fraction contains the rest of the carbon (42 per cent) in the proteins of the cell. Only traces of phosphorus are present in this fraction.

Kinetics of incorporation. When radiophosphorus is added to a growing culture of *T. utilis,* the rate of incorporation of the P^{32} into the TCA-soluble fraction exceeds the growth rate by a factor of 3. The incorporated phosphorus does not exchange with that of the medium, but for the most part is transferred directly to the hot-TCA-soluble fraction. This pool therefore furnishes phosphorus for the entire hot-TCA-soluble fraction, containing 60 per cent of the cell phosphorus. Half of this phosphorus is required for the nucleotides, the remainder is bound in an unknown compound or compounds which require hot TCA for their extraction.

Figure 13 shows the rate of incorporation of the P^{32} into the cold-TCA-soluble fraction, the growth rate of the cells during the incorporation period, and the rate of incorporation into the hot-TCA-soluble fraction. The curves describe the approach to the equilibrium condition in which all the phosphorus of the fractions is radioactive. If the rates were directly propor-

tional to the growth rate, the experimental points would follow the curve labeled "growth." The lower curve describes the theoretical rate of incorporation of P^{32} into the hot-TCA-soluble fraction assuming all the P^{32} to be derived from the TCA-soluble pool. The curve describing the incorporation of P^{32} into the cold-TCA-soluble fraction appears to be a simple exponential scheme is shown in figure 13. The agreement of the experimental data with this curve is excellent.

Since the incorporation of phosphorus into the cold-TCA-soluble pool precedes the synthesis of the other fractions, it is possible to prepare cells containing most of the P^{32} in the metabolic pool. This is done by briefly immersing exponentially

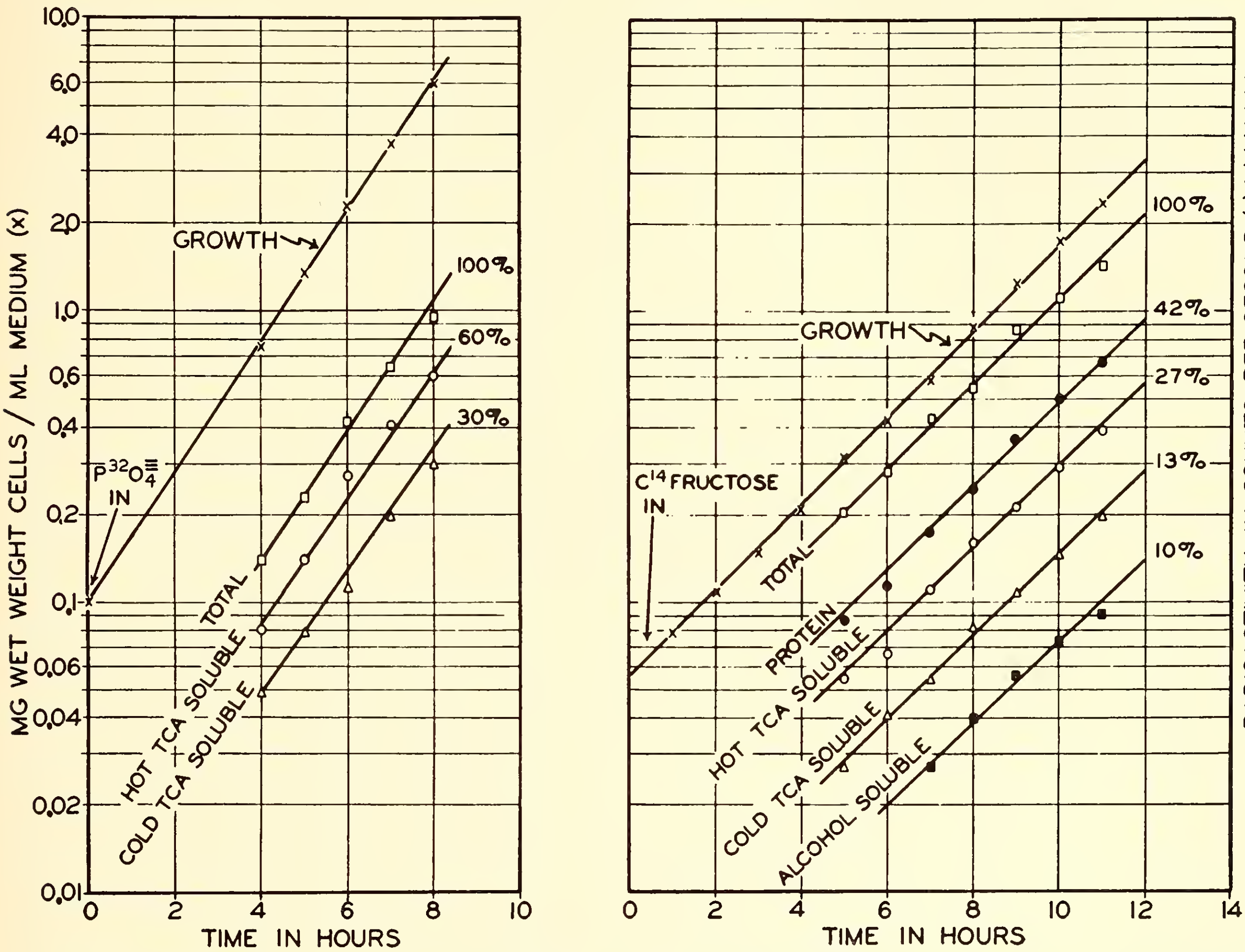

FIG. 12. Distribution of phosphorus (left) and carbon (right) among the chemical fractions of the cell.

with a coefficient three times that of the growth curve. This rapid incorporation in excess of the growth rate is required if the TCA-soluble pool (30 per cent of the cell's phosphorus) incorporates phosphorus in order to form the pool and also provide for the subsequent transfer of phosphorus to the hot-TCA-soluble fraction (60 per cent of the total phosphorus). This scheme is shown in figure 14. The theoretical curve of incorporation of P^{32} into the hot-TCA-soluble fraction according to this growing cells and transferring the cells, after washing, to medium containing nonradioactive phosphorus. The flow of the labeled pool phosphorus to the other fractions of the cell can then be followed. As is shown in figure 15, the P^{32} rapidly leaves the cold-TCA-soluble fraction and for the most part appears in the hot-TCA-soluble fraction. The phospholipides, containing about 10 per cent of the phosphorus of the cell, also receive some of the pool P^{32}. There appears to be little or no loss

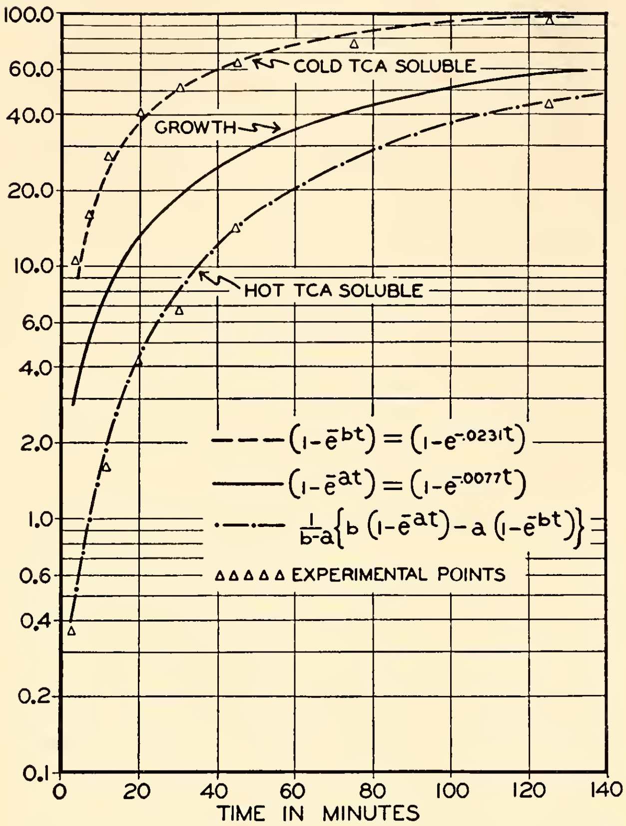

FIG. 13. Rates of incorporation of P^{32} into the cold-TCA-soluble and hot-TCA-soluble fractions of the cell as a function of time after the addition of $P^{32}O_4^{\equiv}$ to an exponentially growing culture of *Torulopsis utilis*. The ordinate is in arbitrary units of radioactivity per gram of cells. Carrier $P^{31}O_4^{\equiv}$ was present in the medium during the entire course of the experiment.

of the labeled P^{32} from the cell to the medium. Interactions between the two components of the hot-TCA-soluble fraction have not yet been resolved, nor has the identity of the unknown phosphorus compounds been established.

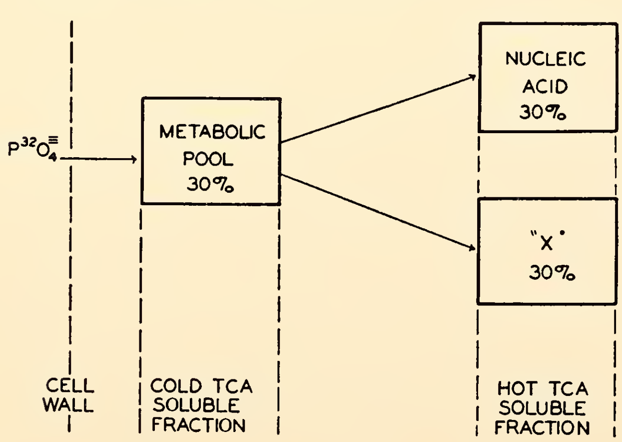

FIG. 14. Diagram of the transfer of labeled phosphorus in *Torulopsis utilis*.

Similar kinetics of formation and transfer are observed when C^{14} fructose is used as the tracer. Figure 16 shows the incorporation of C^{14} into the metabolic pool at a rate 5.25 times the growth rate. The hot-TCA-soluble fraction also incorporates carbon at rates in excess of the growth rate, but this incorporation is not a simple exponential function.

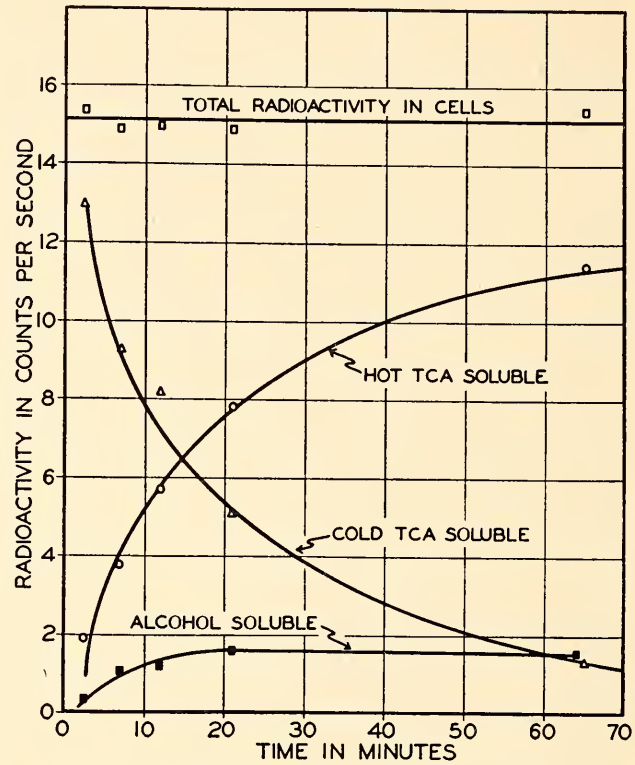

FIG. 15. The transfer of labeled phosphorus from the cold-TCA-soluble pool to the hot-TCA-soluble and alcohol-soluble fractions of the cell. During the time course of this experiment no labeled phosphorus was lost to the medium.

The incorporation of the C^{14} into the proteins of the cell is slower than the growth rate and must therefore be derived from some preformed unlabeled pool during the earlier periods of the experiment. If the simplified model shown schematically in figure 17 were correct, then the expected rate of formation of the intermediate pool would be 4.25 times the growth rate.

It is not surprising that the observed rate of formation exceeds the expected rate of formation based on this simplified model, since it is well known that purines

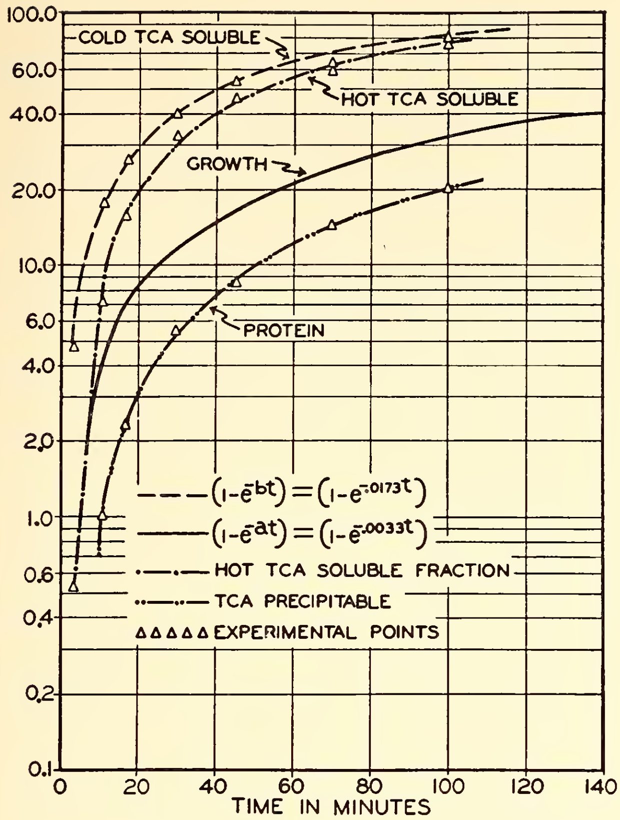

FIG. 16. Rates of incorporation of C[14] into the cold-TCA-soluble, hot-TCA-soluble, and cold-TCA-precipitable fractions of the cell as a function of time after the addition of C[14] fructose to an exponentially growing culture of *Torulopsis utilis*. Symbols as in figure 13.

and pyrimidines derive some of their carbon from amino acids. Indeed, we have observed the transfer of some of the pool carbon both to the hot-TCA-soluble fraction and to the alcohol-soluble fraction of the cell (phospholipides and alcohol-soluble proteins).

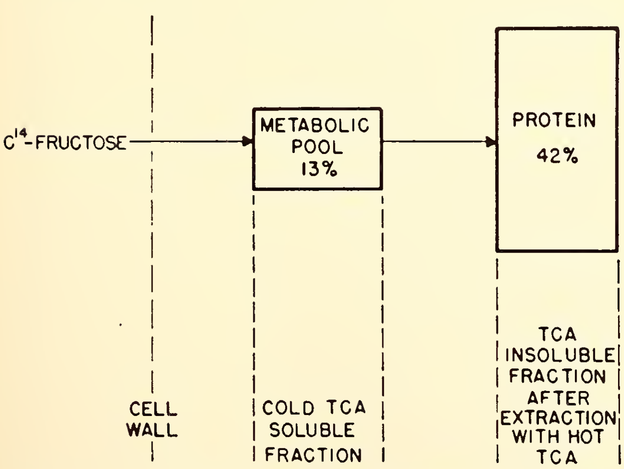

FIG. 17. Diagram of the transfer of labeled carbon in *Torulopsis utilis*.

When the TCA-soluble pool carbon is labeled and the loss of C[14] from the pool is followed, the validity of the above concepts can be demonstrated. Figure 18 shows cells containing 70 per cent of incorporated C[14] from randomly labeled fructose in the TCA-soluble pool. Transfer of these cells to unlabeled medium resulted in a rapid loss of the pool radiocarbon, 50 per cent being lost in the first

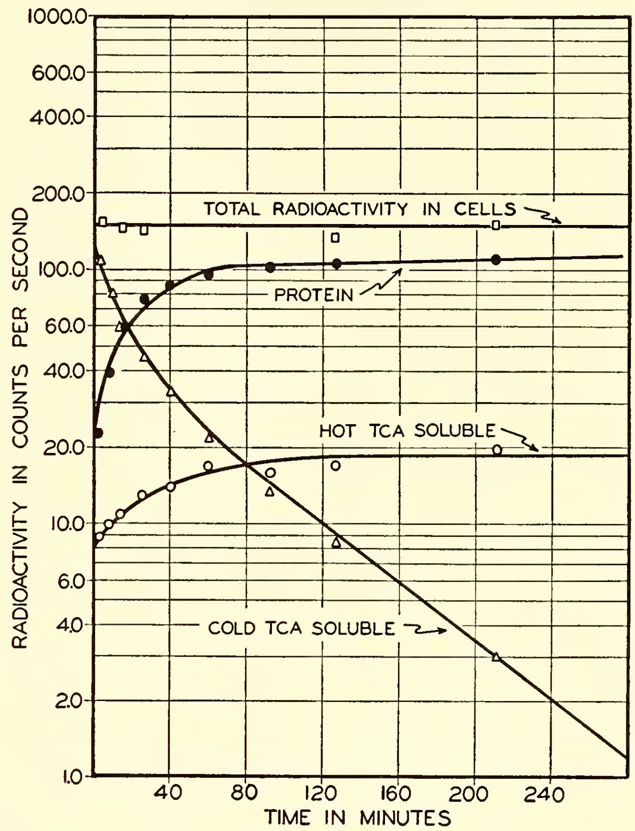

FIG. 18. The transfer of C[14] from the cold-TCA-soluble pool to the hot-TCA-soluble and cold-TCA-precipitable fractions of the cell as a function of time.

20 minutes. The major portion of the carbon appears in the proteins and to a lesser extent in the hot-TCA-soluble fraction and the alcohol-soluble fractions. Very little of the labeled carbon is lost to the medium.

Not all the carbon in the hot-TCA-soluble fraction is derived from the TCA-soluble pool. This is evident from a comparison of figures 16 and 18. In figure 16 it is shown that the rate of incorporation of exogenous C[14] into the hot-TCA-soluble

fraction is rapid, greatly exceeding the growth rate, whereas the rate of incorporation of C^{14} into protein is less than the growth rate. In figure 18 only a small part of the pool carbon appears in the hot-TCA-soluble fraction, and the major portion is transferred to the proteins. Furthermore, if the amino acid pool were the only intermediate for the hot-TCA-soluble fraction, the rate of incorporation of exogenous C^{14} fructose carbon would necessarily greatly exceed the rate observed (fig. 16).

A more complete scheme for the incorporation and transfer of carbon is shown

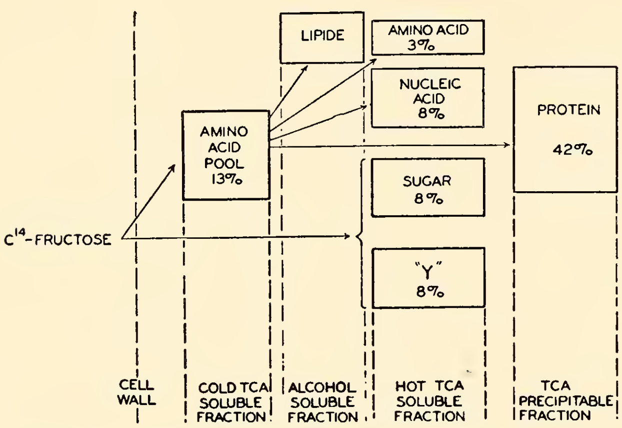

Fig. 19. Diagram of the transfer of labeled carbon in *Torulopsis utilis.*

in figure 19 and is consistent with the results described.

Some interrelations have been observed among the components of the hot-TCA-soluble fraction. When C^{14} adenine is used as the tracer, the incorporation of C^{14} is directly proportional to the growth rate, as shown in figure 20. The C^{14} incorporated was identified by chromatography as adenine and guanine. These results indicate that during exponential growth the rate of formation of at least two of the nucleic acid bases is slow as compared with that of other components of the hot-TCA-soluble fraction, and that the nucleic acids are end products of biosynthesis.

On the other hand, the rate of incorporation of C^{14} from C^{14} fructose into the total hot-TCA-soluble fraction exceeds the growth rate by at least a factor of 3. Chromatographic examinations were made of the hot-TCA-soluble fractions obtained from exponentially growing cells during the early period following the addition of C^{14} fructose to the medium. The incorporated C^{14} first appeared in a fraction shown in the scheme (fig. 19) as "Y." These data show that one of the rapidly formed constituents in the hot-TCA-soluble fraction is "Y."

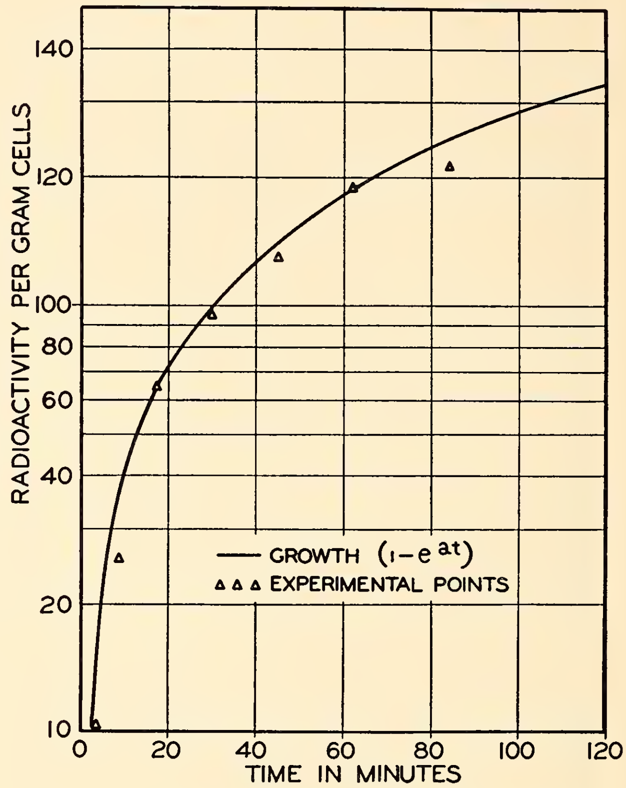

Fig. 20. Rate of incorporation of C^{14} from C^{14} adenine by exponentially growing *Torulopsis utilis* cells.

The detailed chemical relations between the carbon and the phosphorus in the intermediate pools are not known.

The "free amino acid pool." The amino acids making up the metabolic pool are not "free amino acids," able to diffuse out of the cell and exchange with exogenous material. On the other hand, the cell is permeable to amino acids, and exogenous amino acids may diffuse across the cell membrane and compete with fructose carbon in the biosynthesis of protein. These amino acids, however, cannot compete or exchange with the amino acids already in the pool. These conclusions are demon-

strated by the following type of experiment. It has been shown that exponentially growing cells, briefly immersed in C^{14} fructose, washed, and transferred to nonradioactive medium, transfer their radioactive pool carbon to cellular proteins. This transfer of the pool carbon occurs at the same rate even when amino acids are present at high concentrations in the external environment. In such experiments the specific radioactivities of individual amino acids in the protein are the same whether the competitor is present or not.

Figures 15 and 18 show that there is no appreciable loss of either P^{32} or C^{14} from this pool during the transfer periods observed. Cold TCA or alcohol is required to liberate both the carbon and the phosphorus from the cell, a fact which indicates that compounds other than free amino acids or inorganic phosphorus are contained in this fraction. Radioautographs of chromatograms of the unhydrolyzed TCA-soluble fraction obtained from cells labeled with P^{32} show at least seven distinct regions containing the radiophosphorus.

What chemical associations these amino acids and phosphorus have with the organized protoplasm of the cell has not yet been determined. Peptide bonds probably are not the binding agents, since cold TCA does not readily degrade such bonds. The fact that hot-TCA-resistant compounds can be isolated provides hope that they can be identified. Such information, together with the kinetics described, can lead to a more precise interpretation of the way in which living yeast cells synthesize the macromolecules of nucleic acid and proteins. At present it is certain that most of the carbon of the constitutive proteins is derived from the cold-TCA-soluble pool and that all the phosphorus of the hot-TCA-soluble fraction is also derived from this pool. These studies with intact growing cells provide a quantitative and necessary foundation for further investigations of the mechanisms of macromolecule synthesis.

Cell Fragments

Studies of living cultures of organisms can reveal the plot according to which metabolic activity takes place. They do not specify the roles played by the various subcellular structures, however, nor do they show directly how these structures interact to yield the activities observed in the living cell. It is thought that investigations of the relation between subcellular structures and functions may contribute to the solution of these problems. The usual chemical fractionation procedures, which employ strong acids or other drastic conditions, are not suitable for the isolation of cell structures or for the study of loosely bound or adsorbed materials. For example, the materials extracted by TCA are simple free compounds after extraction, but it is certain that many of these are not free as they exist in the intact cells. Instead, they are adsorbed and in this state undergo biologically important reactions. Procedures are therefore needed which will disrupt the cells and liberate cell components but which will also preserve the loose bonds between small and large molecules.

Some progress has been made toward the development of suitable methods for the isolation in good yield of characteristic cell components: cell walls, high-molecular-weight constituents, and low-molecular-weight compounds. Analyses have been made to characterize these components, and preliminary studies have been carried out to investigate some of their functions.

Disruption of bacteria and preparation of cell fractions. Escherichia coli may be efficiently broken by means of the French pressure cell to yield a turbid, fluid suspension. On centrifugation at low speed ($\cong$3000 g), nearly all the remaining viable cells and larger cell debris are sedimented. The still turbid supernatant fluid after centrifugation at high speed ($\cong$10,000 g) yields a pellet of cell walls and an opalescent, straw-colored liquid.

By cycling the cell-wall fraction through low- and high-speed centrifugations, prep-

arations may be made containing one bacterial cell per 10,000 to 30,000 cell walls. These preparations show only an occasional cytoplasmic particle in the electron microscope. A typical preparation contains approximately 10 per cent of the bacterial protein.

The straw-colored high-speed supernatant can be fractionated by paper-strip electrophoresis, salting out, or alcohol precipitation at low ionic strength in the presence of divalent cations. It contains all the nucleic acid and approximately 80 per cent of the bacterial protein. The high-molecular-weight substances in this fluid readily pass through a membrane filter of 150 mμ average pore size, but do not pass through membrane filters of 20 to 30 mμ average pore size. The fluid evidently contains particles of larger size than, for example, serum proteins.

Other methods of cell rupture have also been tried. Grinding with glass, alumina, or carborundum, or sonic disintegration, has generally resulted in poor yields of disrupted cells. A method in which the cells are frozen in water and cooled to $-80°$ C, then subjected to pressures of 4000 to 10,000 pounds per square inch, results in efficient disruption but also gives highly viscous suspensions which are not easily processed further. It is of interest that the "freeze-squeeze" product differs from the pressure-cell product. The high viscosity of the "freeze-squeeze" product is presumably due to the solubilization of nucleoprotein liberated during the disruption of subcellular particles.

Pressure-cell disruption of bacteria yields the cell components quantitatively. Moreover, the cells can be disrupted by this procedure at low temperatures in the same salt solutions used for their culture, in other aqueous solutions, or in solutions of organic solvents.

Properties of the cell walls. Cell walls of *E. coli* have also been prepared and studied by other investigators. It is known from this earlier work that the cell walls are composed of carbohydrates, lipides, and amino acids and are acid-hydrolyzed with difficulty. Our experience shows that they comprise about 10 per cent of the cell protein and have the same kinds and essentially the same relative amounts of amino acids as the whole cell. On partial hydrolysis they liberate glycine rapidly and valine slowly, as do whole cell proteins. A well-packed pellet of cell walls contains 90 per cent water, whereas a pellet of cells contains only 75 per cent water. The walls in suspension show marked light scattering. In ultraviolet light there is superimposed on the scattering spectrum an absorption band at 275 mμ. Differential ultraviolet spectrophotometry of native cell walls shows that the phenolic hydroxyl group of tyrosine is not free to ionize. It may therefore take part in cross-linking between peptide strands or between proteins and carbohydrates or lipides. Chemical determinations of free amino groups in the cell walls have shown that the epsilon-amino group of lysine is the most abundant, that one of the two amino groups of diaminopimelic acid appears to be free, and that free amino groups from other amino acids all together occur at less than one-twentieth the frequency of lysine groups.

Cell walls can be labeled by growing cells in the presence of labeled substrates such as $Na_2S^{35}O_4$ or C^{14} fructose. However, attempts to demonstrate metabolic activity of cell-free preparations of cell walls by measuring incorporation of carbon from radioactive proline, aspartic acid, glucose, fructose, or adenine were unsuccessful. The experiments were nevertheless significant, since they demonstrated that the adsorption of labeled amino acids is not simple adsorption by the external cell wall.

Properties of the high-speed supernatant solution. The supernatant solution remaining after centrifugation of disrupted cells at 10,000 g is rich in protein and nucleic acid. It has been characterized by means of salting-out procedures, precipitation with alcohol solutions containing divalent

cations, and paper-strip electrophoresis. A few studies of its metabolic properties have also been carried out.

Salting out of the high-molecular-weight substances in this solution begins at about one-fifth saturation with neutral ammonium sulfate and is essentially complete at three-quarters saturation. By plotting the amount of protein precipitated against the concentration of ammonium sulfate, a convenient protein precipitation diagram can be constructed. If a metabolic activity, for example an enzyme action of the precipitated materials, is also measured, the results may be superposed on the diagram, revealing at once with what proportion and what kinds of proteins the activity is correlated. This technique was used to determine whether the induced formation of the enzyme lactase (β-d-galactosidase) resulted in the production of only the enzyme protein, or whether in fact other kinds of protein were produced. In order to distinguish newly formed proteins from old ones, radioactive sulfate, which is used in protein synthesis, was supplied to a culture simultaneously with the inducer, lactose. After a few minutes the culture, which had not detectably increased in optical density or given rise to new cells by division, was harvested and processed by pressure disruption and centrifugation.

The high-speed supernatant solution contained all of the newly formed enzyme, lactase. A protein precipitation diagram was prepared, on which the results of enzyme analysis and protein radiosulfur determinations were superposed. It was found that the enzyme precipitated over the relatively narrow range from 30 to 40 per cent saturation with ammonium sulfate, whereas the sulfur radioactivity exactly followed the precipitation pattern of all the cell proteins. Thus it was demonstrated that during the induced formation of the enzyme lactase, many kinds of protein are formed in addition to the enzyme protein.

The high-speed supernatant solution may also be fractionated in the presence of divalent cations. If the solution is adjusted to pH 5.8 at a final concentration of 0.02 M barium acetate, about half the protein and two-thirds of the nucleic acid precipitate. If the enzyme lactase is present, it will remain in solution together with other proteins. When ethanol is added to 20 per cent by volume at $-5°$ C, about half the barium-soluble protein and the remaining nucleic acid are precipitated. Lactase, when present, is found in this precipitate. The remainder of the protein may be precipitated by adding zinc acetate to the alcoholic solution. Each of the precipitates can be redissolved in solutions containing chelating agents which sequester the divalent cations. The several fractions may be further subdivided by means of paper-strip electrophoresis. The divalent cation precipitation procedure has been used especially to purify the enzyme lactase. It is possible to prepare this enzyme by this procedure in 80 to 90 per cent yield and to achieve a 30- to 40-fold purification. Doubtless other bacterial proteins can be purified and isolated by similar procedures.

Since the high-speed supernatant solution represents all the cell substance except the cell walls, it was of interest to attempt to determine whether it could metabolize amino acids and nucleic acid components for the synthesis of macromolecules. Experiments with radioactive proline, aspartic acid, and adenine have so far failed to demonstrate a protein-synthesizing capacity of the high-speed supernatant solutions or of mixtures of this material and cell walls.

Intact bacteria suspended in the high-speed supernatant solution also fail to incorporate C^{14} proline or C^{14} adenine at characteristically high rates, although they grow and divide at the characteristic exponential rate. It appears that the high-speed supernatant solution contains substances which can penetrate the intact cell and be utilized in preference to proline and adenine. The opportunity is afforded, therefore, to study pressure-cell bacterial

extracts by means of the isotopic competition method and to gain information about labile and elusive intermediates in macromolecule synthesis.

Role of Peptides in Protein Synthesis

One theory of protein synthesis holds that amino acids are bound together into small peptides, and that the small peptides are linked into larger peptides and finally linked into the polypeptide chain of the protein. According to these ideas one might expect to find peptides as intermediates of protein synthesis; cells in which protein synthesis was blocked might accumulate peptides; and the cells might prefer to incorporate peptides rather than free amino acids. Several experiments were carried out during the year to test these possibilities.

A group of C^{12} glycine peptides were used as isotopic competitors with C^{14} glucose. Chromatograms showed that the peptides supplied all the glycine required by the cell as well as all the other amino acids of the peptide. Thus, if C^{12} glycylleucine was present, neither glycine nor leucine contained C^{14} from glucose. As only a small portion of the protein-bound glycine or leucine is in the form glycylleucine, it is evident that the peptide was rapidly broken down to the free amino acids and used largely after degradation. Chromatography of the medium also showed that the peptide was almost completely split. Similar results were obtained with cysteinylglycine, glycylalanine glycylphenylalanine, glycylglycine, and triglycine. Specific incorporation of labeled peptides might be possible to observe, but the isotopic competition experiments do not encourage anyone to undertake the major effort required to isolate the peptides. It is obvious that the incorporation would be very inefficient and that most of the peptides would be degraded to free amino acids.

One attempt was made to observe small peptides as a cellular component. A careful examination of the TCA-soluble fraction of the cell showed that unusual movements on paper chromatograms of a number of ninhydrin-positive spots, previously suspected to be peptides, were actually due to the presence of traces of TCA. When the TCA was completely removed by using a Dowex 50 ion-exchange column, all the observed ninhydrin-positive material could be identified as free amino acids and glutathione.

Neither could any accumulation of peptides be observed in metabolically blocked cells which could not synthesize protein. Nitrogen-, sulfur-, and magnesium-deficient media were used to prevent protein synthesis. In no case could any peptide accumulation be observed. These media were also used to look for exchange of free amino acids with protein-bound amino acids. No exchange was found.

Two mutants were also used, one requiring phenylalanine and the other methionine. These mutants could not synthesize protein in the absence of the one required amino acid, but peptide did not accumulate, either in the cell or in the culture fluid.

Having obtained only negative evidence on peptide utilization, we thought it desirable to repeat again the one kind of experiment which has shown an indication of preferential utilization of peptides. A culture of *E. coli* cells was grown in the presence of C^{14} glucose to give uniformly labeled protein. One half of this protein was hydrolyzed briefly, and a chromatogram showed that the hydrolyzate contained mostly large peptides with only a small quantity of free amino acids. The other half was hydrolyzed 18 hours to free amino acids. These hydrolyzates were then used to supplement glucose media both with and without a large excess of unlabeled free amino acids. The results (table 17) agree completely with unpublished experiments of Abelson carried out in 1952. The addition of C^{12} amino acids did not reduce the incorporation of radio-

activity from the partial hydrolyzates as much as it did that from the complete hydrolyzate. Evidently there is some preferred incorporation of amino acids found in large peptides. In view of the other negative data on peptide accumulation and the observed adsorption of free amino acids, this preferential utilization of large peptides does not seem to be of major importance in protein synthesis. At present it appears that the template idea is more nearly correct than the peptide idea.

which supplement those of the past. Some further investigation has been carried out with *Staphylococcus aureus,* which is entirely different from *E. coli* in regard to permeability. During these experiments it was noticed that the permeability of *E. coli* to $SO_4^{=}$ ions is not the same as previously measured. In contrast, the measured permeability to many other small molecules and ions has not altered.

Very briefly, the method used for measurements of permeability is as follows: A weighed, centrifuged pellet of cells (0.5 to 1.0 gm) is suspended in a known volume of solution (0.5 to 1.0 ml) containing a labeled compound; the suspension is centrifuged, resuspended in unlabeled solution, and again centrifuged; assays for the concentration of the labeled material are carried out on each of the solutions, and in this way the fraction of the volume of the pellet which is accessible to the labeled compound is measured.

TABLE 17

Incorporation of hydrolyzates of C^{14}-labeled protein

Tracer	Competitor	Radioactivity incorporated	
		Nucleic acid	Protein
C^{14} protein partial hydrolyzate..........	None	78	520
	C^{12} amino acid mixture	45	370
C^{14} protein complete hydrolyzate........	None	148	1320
	C^{12} amino acid mixture	56	520

Permeability

Escherichia coli has a cell wall which can be separated from the rest of the cell material as a structural entity. Consequently, when a compound added to the growth medium is found to be biologically inert, one possible explanation is that it cannot penetrate the cell wall. Also, when a number of compounds are found to be concentrated within the cell, it must be decided whether they simply cannot penetrate the membrane to diffuse out, or whether some kind of binding is involved.

During the past years the permeability of *E. coli* and *T. utilis* has been measured with many low-molecular-weight compounds and ions. In practically all cases the cell wall appears to be permeable and to have little effect on the passage of material in and out of the cell. These permeability measurements, however, are never finished. Whenever new compounds are investigated, their ability to permeate cell walls needs to be determined. Accordingly, some additional permeability measurements have been made during the year

For *E. coli* the space accessible to practically all low-molecular-weight substances is 75 per cent of the cell volume, which is roughly the same as the water content of the cell. Thus, the term "water space" has come into use. Since different values have been obtained for different substances in *S. aureus,* the term "accessible space" will be used to avoid confusion, and the volume of this space will be expressed in percentage of the volume of the centrifuged cell pellet.

Staphylococcus aureus. Accessible-space measurements have been carried out on *Staphylococcus* with the following sub-

stances (the results being shown in parentheses): gamma globulin (26 per cent); dextran, a high-molecular-weight polysaccharide (29 per cent); $SO_4^=$ (39 per cent); glutamic acid (38 per cent); D_2O (80 per cent). These values represent the averages of many determinations, with some variations in growth conditions and in concentration of the substances concerned. There seems to be very little doubt that the fraction of the pellet volume accessible to $SO_4^=$ and glutamate is larger than that accessible to the high-molecular-weight substances. These results indicate that a pellet of *Staphylococcus* cells contains a true intercellular space (accessible to all substances) of 26 to 29 per cent of its volume. In addition to this, there is a small volume (about 10 to 15 per cent) of unknown nature (possibly a slime layer) which is accessible to $SO_4^=$ and glutamate. Another 40 per cent of the pellet is accessible to D_2O but not to the other substances tested. Finally, there is a small volume (20 per cent) which is completely inaccessible and roughly equivalent to the volume of the cellular material when dried.

If a large part of the cell volume were enclosed, as these data indicate, in a semipermeable bag, it would be expected that shrinkage would occur in high salt concentrations. Ten per cent NaCl causes a shrinkage to about half the original volume of the pellet, and the original volume is approached after washing in isotonic solution.

Torulopsis utilis. Measurements have previously been made of the accessible space of *T. utilis* to fructose (72 per cent), valine (68 per cent), and aspartic acid (65 per cent). These measurements show that this yeastlike cell is freely permeable to small molecules and thus is more similar, as regards permeability, to *E. coli* than to the gram-positive *Staphylococcus.*

Escherichia coli. The accessible space of *E. coli* has been directly measured for valine (70 per cent), proline (70 per cent), sucrose (74 per cent), fructose (76 per cent), and glucose (72 per cent). In addition, the kinetics of amino acid uptake give evidence supporting the concept that the cell is permeable—i.e., that low-molecular-weight compounds enter by free diffusion.

Experiments on the kinetics of proline uptake, similar to those described in a previous section, but at very low proline concentrations, indicate that the rate of uptake of proline is within an order of magnitude or so of the rate of free diffusion of proline in water solution into a sphere of water one micron in diameter. The question whether any other process sets a limit on the rate of uptake of proline cannot yet be resolved.

Over a period of several years' work on the permeability of the *E. coli* cell in this laboratory, literally many dozens of individual measurements of the space accessible to the sulfate ion have been made using these same procedures, always with the same result, 75 ± 5 per cent. Since last fall, however, the measured values have centered around 32 per cent with a spread of ± 5 per cent. Numerous attempts have been made to track down the cause of this change, without success. The same value was found for cells grown from an inoculum of strain B supplied by the American Type Culture Collection and for cells grown from a freeze-dried preparation of our usual strain B stored since 1949. The change is apparently not caused by trace substances now present in our growth media, and, as far as we know, has occurred only for the sulfate ion.

The fact that the permeability characteristics of *E. coli* are very different from those of the *Staphylococcus* is shown by the observation that there is no measurable shrinkage of *E. coli* in high salt concentrations, whereas with *Staphylococcus* there is a partly reversible shrinkage of about 50 per cent.

OPERATIONS AND STAFF

Co-operative Work of the Department

We have continued our co-operative work with various organizations including the Department of Defense, Geological Survey, Geophysical Institute of Huancayo (Peru), National Bureau of Standards, National Institutes of Health, National Research Council, National Science Foundation, Catholic and Tulane Universities, University of Pennsylvania, Mount Wilson and Palomar Observatories, and Cavendish Laboratory (England). Equipment was loaned to the Institute of Theoretical Astrophysics of Oslo, Norway. We have collaborated with the International Union of Geodesy and Geophysics and the International Scientific Radio Union. Foreign visitors, some on Carnegie Institution fellowship appointments, have come from Australia, Denmark, England, Norway, and Pakistan.

The investigation of mineral ages was continued with the Geophysical Laboratory.

We have had continued assistance in our cosmic-ray program from the observatories at Cheltenham, Maryland; Christchurch, New Zealand; Climax, Colorado; Godhavn, Greenland; Huancayo, Peru; and since September 1, 1954, from the University of Mexico, Mexico, D. F.

Contracts with the government have been continued, without subsidy, for investigations of the earth's crust, cosmic rays, and the measurement of mineral ages, particularly in Pre-Cambrian rocks; a new contract for the procurement of certain enriched isotopes for nuclear studies was made in December 1954.

Several staff members are serving on panels of the U. S. National Committee, International Geophysical Year. One member has assisted in reviewing the program of the Army in combat developments and is serving on the Advisory Panel on General Sciences of the Department of Defense; he is also chairman of the Advisory Panel on Radio Astronomy of the National Science Foundation, and heads the National Academy Advisory Committee to the Federal Civil Defense Administration. One member is serving as chairman of the U. S. A. National Committee, International Scientific Radio Union, and has continued as director of the Institute of Radio Engineers for Region III. Another staff member has continued his full-time research work for the government.

The Department was represented abroad at meetings of the International Nuclear Physics Conference, International Scientific Radio Union, International Union of Geodesy and Geophysics, and Conference on Ionospheric Physics.

Administration and Operation

We have continued to publish the *Journal of Geophysical Research,* subsidized in part by the Institution.

Leases were continued for parts of various farms for research work concerned with radio astronomy and the ionosphere.

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——— G. R. TILTON, G. L. DAVIS, and L. T. ALDRICH. Comparison of radioactive age measurements on pegmatites. (Abstract) Trans. Amer. Geophys. Union, vol. 36, p. 533 (1955).
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Major Publications

Studies of biosynthesis in *Escherichia coli.* By R. B. Roberts, P. H. Abelson, D. B. Cowie, E. T. Bolton, and R. J. Britten. Carnegie Inst. Wash. Pub. 607. Octavo, xiv + 521 pp., 114 figs. (1955).

STAFF AND ORGANIZATION

Scientific Staff

Director: M. A. Tuve.

Staff Members

Geophysics: L. T. Aldrich, B. F. Burke, J. W. Firor, S. E. Forbush, J. W. Graham, E. A. Johnson,* H. E. Tatel, G. R. Tilton, E. H. Vestine, H. W. Wells, G. W. Wetherill.

Laboratory and Biophysics: E. T. Bolton, R. J. Britten, D. B. Cowie, N. P. Heydenburg, R. B. Roberts, G. M. Temmer.

Guests, Associates, Fellows, and Visiting Investigators: S. J. Ahmed, Pakistan; A. Bohr, Institute for Theoretical Physics, Copenhagen, Denmark; Mrs. J. K. Doherty, National Institutes of Health; W. R. Duryee, National Institutes of Health; T. Ecklund; L. B. Flexner and Mrs. J. B. Flexner, University of Pennsylvania; K. L. Franklin, University of California; J. B. French, University of Rochester; P. W. Gast, Lamont Geological Observatory; P. J. Hart, Harvard University; H. L. Helfer, Yerkes Observatory; P. M. Jeffery, University of Western Australia; J. Z. Klose, Naval Academy; R. D. McAfee, Tulane University; G. H. Munro, Radio Research Board of Commonwealth Scientific and Industrial Research Organization, Sydney, Australia; L. Owren, Institute of Theoretical Astrophysics, Oslo, Norway; F. Rector, University of Texas; Mrs. I. Z. Roberts; F. G. Smith, Cavendish Laboratory, Cambridge, England; M. Sugiura, University of Alaska.

* On leave of absence for government work.

Operating Staff

Administrative: M. B. Smith, W. F. Steiner.

Office and Clerical: Mrs. C. C. Ator, Mrs. M. P. Blanchard,‡ Mrs. M. Q. Chapin, W. N. Dove, W. C. Hendrix,‡ C. S. Leonard, Jr., Mrs. A. P. Moffett, D. J. O'Rourke,‡ Miss H. E. Russell.

Instrument Shop: B. J. Haase, L. A. Horton, J. G. Lorz.

Research Assistants and Laboratory Assistants: S. J. Buynitzky, H. E. Cronin,‡ J. B. Doak, E. T. Ecklund, Miss E. F. French, R. E. Hewitt, P. A. Johnson, C. A. Little, Jr., R. W. Reuschlein, W. E. Scott, Mrs. B. P. Walton.

Computer: Miss I. Lange.

Maintenance: C. Balsam, C. R. Domton, P. C. Hovgard, E. Quade, S. Swantkowski.

Part-time and Temporary Employees: Seventeen part-time and temporary employees were engaged during the year, usually for short periods, to assist in the office and laboratory work.

‡ Resigned.

GEOPHYSICAL LABORATORY

Washington, District of Columbia

PHILIP H. ABELSON, *Director*

The enormous post-war increase in scientific research has altered the environment in which the Geophysical Laboratory operates. In past years our work was the major effort in geochemical and petrological research. Today several universities have active and excellent programs in this field. In terms of numbers of research workers we now constitute perhaps five per cent of our field. If we are to continue to play a significant role, it must be on the basis of qualitative excellence and of pioneering new and significant areas.

In our efforts to do good work we have several advantages. Our group is somewhere near optimum size for a research organization active in a limited area. We are free to do fundamental research unhampered by the pressures that attend work in industry and government or by the teaching load that often handicaps the university scholar. By reason of the flexibility of the Carnegie Institution of Washington, we can conduct experiments in laboratory management and operation.

A laboratory such as ours needs frequent transfusions of some of the values of the university. It needs the presence of the young, though not in the overwhelming numbers found at a university. It needs frequent seminars on subjects other than those dealt with by the laboratory group. It needs close contact with other scholars. During the past year several steps have been taken which are aimed at creating a stimulating environment. The first is exchange of staff members with other academic groups. One of our staff members, Chayes, served for a quarter-year as a visiting professor at the California Institute of Technology. Later, one of the men at that Institute will spend some time with us. The second action was creation of a joint Geophysical Laboratory–Johns Hopkins University predoctoral fellowship program under which men will do thesis research here and obtain their Ph.D. degrees from Johns Hopkins. Negotiations for a similar arrangement with the Massachusetts Institute of Technology have recently been completed. In addition, several graduate students from Johns Hopkins spend two days a week here learning by working with staff members. A postdoctoral fellowship program has been in operation for some time and is being continued. Much is expected from an expansion and reorientation of the Research Associate program. So far, four Associates have been appointed. Dr. Willard F. Libby, of the U. S. Atomic Energy Commission, is an outstanding physical chemist and leading authority on tritium and carbon-14. He spends such time at the Laboratory as duties at the Commission permit. Dr. C. E. Tilley, Professor of Mineralogy and Petrology at Cambridge University, will spend three months here in early 1956, while preparing a book on metamorphism. Dr. Hans Ramberg, of the University of Chicago, a brilliant geologist with whom members of the staff have often disagreed, will spend several weeks at the Laboratory on a number of occasions, thus permitting complete exploration of areas of agreement and disagreement. Professor Gordon J. F. MacDonald, of Massachusetts Institute of Technology, is highly competent in theoretical geology and will give staff members the benefit of frequent consultations.

The research program of the Laboratory continues to be fruitful. The year has been marked by an unusual amount of work on the sulfide minerals and their close relatives, the selenides and tellurides. A broad study of the system copper—iron—sulfur has been completed and is being prepared

for publication. Work has been started on the system iron—nickel—sulfur. A strong dependence of (solid state) inversion temperatures on very slight excesses of silver or tellurium in the compounds Ag_2Te and Ag_5Te_3 has been discovered. (A similar effect had previously been found in Ag_2S; see Year Book No. 45, 1945–1946.) Single crystals of digenite have been synthesized for the first time, and extensive X-ray studies of this compound—apparently very close to Cu_9S_5 in composition—have been completed. A recent suggestion that the iron content of sphalerite (ZnS) could be used as a geological thermometer has been subjected to further testing. It has been found that the mineral pyrite (FeS_2), which is difficult to synthesize at low pressures, forms readily under higher pressures of sulfur vapor; the stability relations of this common and ubiquitous mineral can now be studied systematically. Preliminary experiments on methods of dissolving sulfide ores *in situ* have been made.

Systematic studies of mineral synthesis and the researches in silicate phase equilibria on which they are based continue to form the core about which most of the activity at the Laboratory is centered. Detailed reports of experimental work in the systems Na_2O—Al_2O_3—SiO_2, K_2O—Al_2O_3—SiO_2, K_2O—MgO—Al_2O_3—SiO_2, and Na_2O—Al_2O_3—Fe_2O_3—SiO_2 are being made ready for publication. A preliminary diagram of the subsolidus relations between muscovite and paragonite has been drawn up; the importance of knowledge about the stability of muscovite in the study of metamorphic rocks can hardly be overestimated. Several new occurrences of the sodium mica, paragonite, have been discovered, and it now seems likely that this mineral is considerably commoner than had been thought. Results of a study of muscovite extending over three years have been prepared for publication. A number of new amphibole syntheses have been effected, and study of stability relations in this important group of minerals continues.

Studies in the hydrothermal synthesis of albite have contributed one of the major surprises of the year. This is the discovery of small but easily significant variations in lattice parameters as a function of temperature of crystallization alone. This discovery will require careful re-evaluation of recent hydrothermal experimentation, both at the Laboratory and elsewhere. In much work of this type identification is based largely or wholly on X-ray diffraction measurements of lattice parameters. A similar temperature effect had previously been detected in nepheline syntheses. No explanation of the effect is now available, and it is not known whether synthetic minerals other than nepheline and albite show it. But it is certainly reasonable to suppose that they do.

In statistical petrography the emphasis during the past year has been primarily on the theory and technique of modal analysis. A manual intended for advanced undergraduates and beginning graduate students, and presenting those parts of the technique which either are based entirely on geometrical considerations or have been subjected to adequate experimental appraisal, is now being prepared for publication. A more detailed description of this and other experimental work is given in the following pages.

APPLICATION OF EXTREME PRESSURES TO GEOLOGICAL PROBLEMS

The lower boundary of the earth's crust is fixed by the Mohorovičić discontinuity, at an average depth of 40 km. At this depth the pressure is approximately 10,000 bars, and the temperature locally may be as high as 1600° C in hot magmas. Pressures and temperatures ranging up to these values (10,000 bars and 1600° C) are adequate for laboratory investigation of mineral and rock problems confronting the

field geologist. Earth structure problems, on the other hand, involve a different order of conditions. The pressure at the center of the earth is about 3.6 megabars, and the temperature is estimated to be 3000° C. The experimental pressure-temperature maxima at which *accurate* measurements have so far been made are 25,000 bars and 1200° C (Birch) and 10,000 bars and 1600° C (Yoder). Apparatus devised by other workers have attained 50,000 bars and 600° C (Griggs, Kennedy, Fyfe), 45,000 bars and 800° C (Coes), and 100,000 bars and 3000° C (Hall *et al.*), but it is not possible to obtain accurate measurements of either pressure or temperature in these devices. The highest pressures attained (100,000 bars) are equivalent to a depth of about 280 km, assuming an average rock density of 3.6. Efforts are now being made at the Geophysical Laboratory to design, develop, and construct apparatus in which *accurate* measurements can be made up to 50,000 bars and 1600° C. Equipment now being tested may serve as a guide for designs suitable for even more extreme conditions.

Compressibility of analcite (Yoder, Weir). The most important effect of high pressure is reduction in volume. The compressibility of a mineral or rock may be used in conjunction with its density to obtain information regarding its characteristic seismic velocities. Since dilational and rotational velocities are known at various depths within the earth, some estimate of the composition of the rocks in the interior of the earth may be made. At depths between 200 and 900 km, however, the materials now known which have the requisite elastic properties are not believed to be present on the basis of geological deductions. Birch suggests that the composition need not change drastically at depth if the minerals observed at the surface undergo high-pressure phase transitions to very close-packed structures such as rutile, corundum, and spinel. (It was shown in last year's report that the spinel structure has suitable elastic properties.) Only two phase transitions resulting from compression are known in rock-forming silicates, SiO_2 and $NaAlSi_2O_6 \cdot H_2O$. The nature of a reversible high-pressure transition is indicated in figure 1 for a sample of analcite, $NaAlSi_2O_6 \cdot H_2O$, from Golden, Colorado. The other three samples of analcite gave an abnormal increase in compressibility; such behavior usually precedes a transition. Although the existence of these transitions supports Birch's suggestion, many more experiments are required in which the compressibility of minerals and rocks would be investigated at 100,000 bars and higher. Out of such studies could come an entirely new conception of the interior structure of the earth.

Almandite garnet stability field (Yoder). Another possible product of studies in the high-pressure region is the formation of new mineral species. Pressure favors the formation of minerals having small volume. Minerals whose atoms have high co-ordination are also considered to be favored by pressure, since an atom in high co-ordination occupies less space than one in lower co-ordination. The most famous example of this principle is carbon. The carbon atoms in diamond, the high-pressure form, are in fourfold co-ordination, and those in graphite, the low-pressure form, in threefold co-ordination. Similarly, aluminum can exist in four- or sixfold co-ordination. For example, jadeite, which has aluminum in sixfold co-ordination, breaks down at low pressures into minerals which have aluminum in fourfold co-ordination. The most interesting aspect of minerals having sixfold co-ordinated aluminum and fourfold co-ordinated carbon is that they have defied synthesis until recently. The synthesis problem appears to be one of growth rate rather than of stability range. The nature of the problem is clearly demonstrated by the synthesis of the common garnet almandite, in which the aluminum is in sixfold co-ordination. The preliminary upper stability curve of almandite is given in figure 2. At 10,000 bars pressure and at a temperature close to the

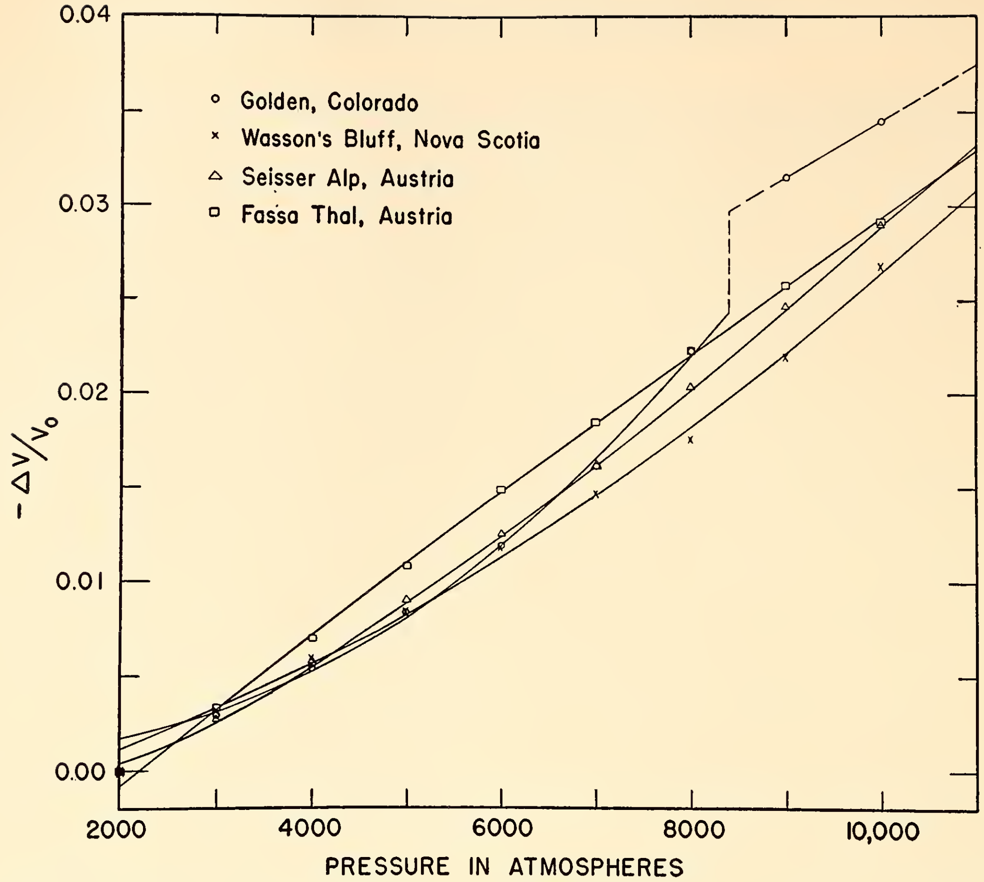

FIG. 1. Relative volume change as a function of pressure of four analcite ($NaAlSi_2O_6 \cdot H_2O$) specimens. Golden, Colorado, analcite shows a high-pressure inversion at 8400 bars. The samples from Seisser Alp, Austria, and Wasson's Bluff, Nova Scotia, have an anomalous increase in compressibility with pressure.

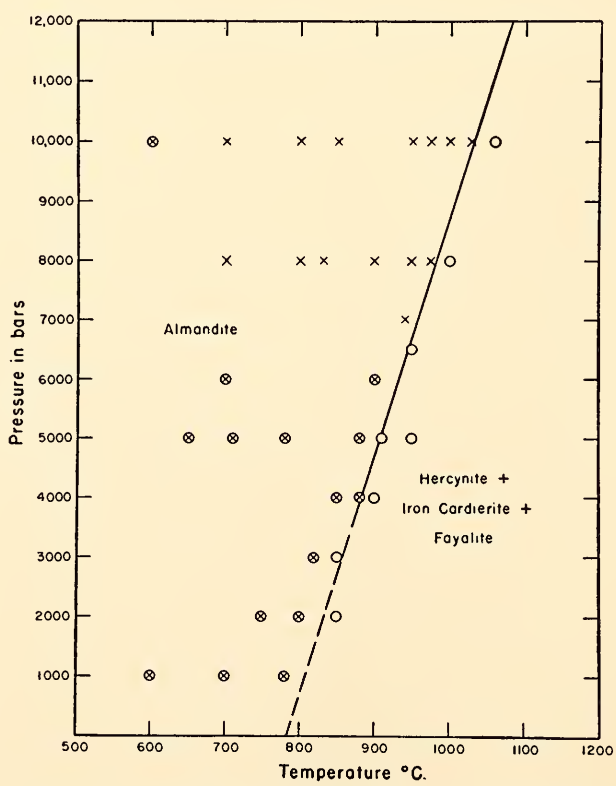

FIG. 2. Preliminary equilibrium curve for the reaction almandite = hercynite + iron cordierite + fayalite. Crosses indicate that garnet was produced; circles, the breakdown products or their equivalent.

upper thermal stability limit, a charge of garnet composition reacts completely in two hours; at 5000 bars, one week is required, and at 1000 bars, several weeks are required for complete reaction. It is concluded from this behavior, as well as from that of other recently investigated mineral systems, that the fastest growth rate occurs at the highest pressure attainable and at a temperature close to the upper limit of stability. Pressure itself slows reactions down, but usually raises the thermal stability limit, and at high temperatures the reaction rate increases manyfold. Application of this concept should facilitate the synthesis of other minerals found difficult to grow.

Perhaps the most important consequences which might flow from studies at high pressures are those which are not now seen. Very high pressures and temperatures doubtless will elicit phenomena previously unimagined.

SULFIDE SYSTEMS AS GEOLOGICAL THERMOMETERS

Temperature of deposition of sulfide ores (Kullerud). Ore deposits have been exploited almost since the origin of man, and speculation concerning their mode of formation was already a lively topic in the days of the ancient Greeks. During the past few decades detailed petrographic studies of ore deposits have shed some light on the processes by which the ores were deposited. From these studies, however, little information could be deduced about the conditions under which the various minerals were formed or about the mechanisms leading to ore formation. Interpretation of textures displayed in nature will be possible only when laboratory experiments have examined the processes taking place in ore bodies.

The composition of solid solutions is a function of the pressure and temperature existing during ore deposition, provided equilibrium conditions were maintained during the period of formation. Since the influence of pressure (that existing in the crust of the earth during ore formation) on composition is normally relatively small, a determination of the composition of such crystals is in effect a measure of the temperature at which they formed. From a number of such determinations made on specimens from a particular deposit, the range of temperature during the ore deposition can be estimated. This kind of temperature determination is improved if, from geological experience, an approximate numerical value can be assumed for the pressure that existed during ore formation.

Recent systematic laboratory investigations of the system FeS—ZnS, which includes the natural minerals pyrrhotite (essentially FeS) and sphalerite (essentially ZnS), show that in the solid state the solubility of ZnS in FeS is negligible, but that of FeS in cubic ZnS varies from about 4 mol per cent at 150° C to about 40 mol per cent at 894° C. The amount of FeS in a natural sphalerite thus provides a measure of its temperature of formation.

When pressure is applied to a solid solution of any composition in this system, the decrease in solubility of FeS in ZnS corresponds to a temperature decrease of 25° C per 1000 atmospheres. In other words, to keep solid-solution composition constant the temperature would have to be raised by 25° C for every additional 1000 atm applied.

Geological field evidence in some cases makes it possible to estimate the pressure existing during ore formation within the limit of ± 1000 atm. In such cases, an uncertainty of $\pm 25°$ C can be attached to the temperatures obtained by use of the FeS—ZnS system.

One of the first goals of further study is to examine systems containing solid solutions which are likely to be contiguous to and to have formed contemporaneously with those of the FeS—ZnS system. This accomplished, it would not be necessary to rely on geological estimates of the pres-

sures existing during ore formation. This possibility has been illustrated in figure 3. Here curve I shows the pressure-temperature relation for a cubic (Fe,Zn)S mix-crystal of any composition. Curve II shows the same relation for a hypothetical mix-crystal formed contemporaneously with the (Fe,Zn)S mix-crystal. The intersection of curves I and II specifies both the tempera-

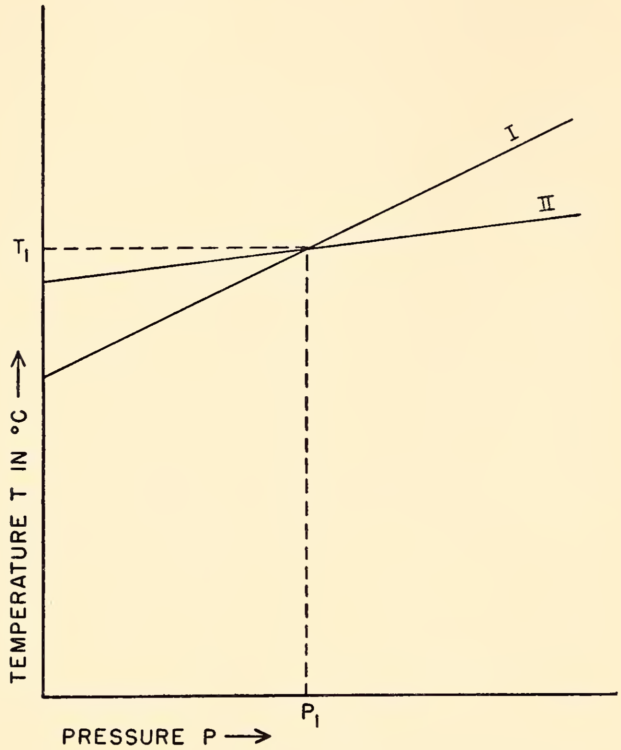

Fig. 3. Hypothetical pressure-temperature relation for two types of contemporaneously formed mix-crystals (I, II). The intersection of the curves specifies both the temperature and the pressure existing when the solid solutions were formed.

ture and the pressure obtaining when the solid solutions were formed.

Piezo thermometers of this kind need not be restricted to use in ore bodies. They might be applied to determine pressures and temperatures governing other geological processes, such as skarn formation, pegmatite formation, and granitization. In numerous cases these systems may provide data about contemporaneously formed silicates and their equilibrium solid solutions. Research on ore minerals and their solid-solution series may thus supplement research on silicates.

Most ore minerals are either sulfides or oxides. The base metals, exclusive of iron and manganese, normally occur as sulfides, and small amounts of many of the base-metal sulfides are widely disseminated through common rocks.

Most iron ores are oxides, and this is also true of certain minor metals, such as titanium and chromium. Like the sulfides, the oxides are widely disseminated as minor or trace constituents in the silicate mantle. Both the sulfides and the oxides thus offer possibilities for research of the kind outlined above.

The sulfide group offers certain experimental advantages, such as rapid reaction rate, simplicity of preparation, and ease of manipulation. It has therefore seemed desirable to use sulfides in pilot studies. These accessible systems will provide information which later may be applied in study of some of the experimentally difficult systems.

The FeS—ZnS system has been used to estimate the temperatures existing during a number of geological processes. By analyzing a number of representative samples containing sphalerite from various small deposits in the Caledonides of northern Norway, a theory, proposed by field geologists, demanding uniform temperature of mineralization has been tested. These sulfide ores occur as flat tabular bodies in the allochthonous schists of the eastern or marginal zone (as opposed to the central zone) of the Caledonides.

Six deposits were carefully sampled. Specimens from five of the deposits showed free pyrrhotite. The temperatures of formation deduced from these specimens all lie within a narrow range of $515° \pm 40°$ C. Specimens from the sixth deposit contained no free iron sulfide, and the temperatures obtained were all 50° to 75° C lower than those obtained from specimens from the first five deposits.

The results support the idea of a uniform mineralization in the Caledonide schists of northern Norway, as deduced from the assemblage of ore minerals and from the mode of occurrence of the ore bodies.

CHEMICAL MINING

Methods of dissolving sulfide ores (Abelson, England). Although many operational procedures have been highly mechanized, principles of mining and ore processing have progressed little in fifty years. Machinery has improved, but the basic pattern of digging a hole in the ground and reaching the ore body has been preserved. The various methods of concentrating ore usually involve flotation, a process long in vogue. This is followed by a smelting operation which differs little from that employed by the ancients.

Some signs of a change are now visible. A new wet process for oxidation of sulfide concentrates has recently been placed in operation which permits easy separation of nickel, cobalt, and copper—something which is very difficult by conventional smelting processes.

Under many circumstances use of wet chemical methods of mining might well be desirable. Costs of conventional mining methods in deep mines can ultimately become prohibitive. If ore is located at great depths below the water table, costs of pumping may be enormous. Furthermore, temperatures at great depths may be so excessive as to limit operations where personnel are involved. In some circumstances costs of chemical methods could be much lower than those of conventional methods. The cost of drilling holes for piping chemicals is only a fraction of that for a shaft.

Precedent does exist for two types of mining involving fluids. The first is removal of salt by dissolving in water to form a brine. The second is the famous Frasch process for extracting sulfur. This is based on melting the sulfur by means of hot water or steam and conducting the material to the surface while it is in the molten state.

Processes which might be employed for ore minerals would probably not be so simple. Most ores occur in water-insoluble form. The largest reserves of copper, nickel, cobalt, lead, zinc, molybdenum, and many other valuable elements are found in the form of sulfides which are not readily soluble.

The problem reduces itself to the discovery of cheap means for dissolving sulfide in both acid and alkaline environments. One possibility applicable under some circumstances is to oxidize the ore underground, using oxygen or compressed air. This would render the ores more amenable to leaching techniques. Study of the oxidation of sulfides at low temperatures in the presence of moisture and air is a project of interest to the geologist. Knowledge of the weathering process is very sketchy at present. Investigation of the oxidation of sulfides is thus of twofold importance. If the wall rock is chemically inert, oxidation with air or oxygen, employing nitric acid as a catalyst, could be quite successful. This process has been shown to be feasible in laboratory studies. A massive ore body might be best dissolved by electrochemical methods. Ore minerals such as galena (PbS), chalcopyrite ($CuFeS_2$), and pentlandite ($(Fe,Ni)_9S_8$) are good conductors of electricity. When made the anode of an electrolytic cell such a mineral goes into solution readily.

Further development of chemical mining can proceed when the basic chemistry and electrochemistry of ore materials are better known.

STATISTICAL PETROGRAPHY

The two limits of modal analysis (Chayes). Estimates of the relative amounts of the various minerals contained in a rock are commonly obtained either by recalculation from bulk chemical analysis or by direct identification and measurement in thin section. In terms of the amount of information usually desired about areal variation in many petrographic units, bulk chemical analysis is very costly. It has the further disadvantage that unless the compositions of the individual min-

erals are known (from previous analysis), the recalculation is necessarily based on theoretical or ideal mineral formulas. The resulting statement is accordingly an estimate of the proportions in which the minerals would be present if they had the compositions assigned to them in the calculation.

Where direct measurements can be made at all, they are not subject to either of these limitations. Their cost is usually negligible in relation to that of bulk chemical analysis, so that their systematic application would make practical the adoption of far more extensive and informative sampling procedures than are now in use in descriptive petrography. Their results are estimates of the amounts of the actual minerals present in the rock, and for this reason are referred to as *modes,* in contrast to the *norms* recalculated from bulk chemical analyses.

A number of years ago a program devoted to the systematic development and exploitation of modal analysis was undertaken. Although little had been done on the subject, either theoretically or experimentally, it was evident that the controlling factor was grain "size" or coarseness. Purely as a practical stratagem, therefore, the program was oriented from the outset toward rocks which most geologists would call "medium" or "medium fine." It soon became clear that the method was extraordinarily rewarding in granitic rocks of this type. Although no suitable measure of grain size was available in rocks of complex fabric, it was not difficult to limit the work to materials everyone would agree were of medium grain. By definition a very fine-grained rock is not usually called granite, and as a matter of common sense one does not ordinarily take the time to analyze a thin section unless it contains a few hundred grain sections.

This still leaves a considerable range of coarseness, a range whose significance depends largely on the purpose of any particular analytical program. If our interest is in mean values, the effect of variation in coarseness will rarely be critical. If, however, we are attempting to estimate variance, it may easily be decisive. And if, as is more commonly the case, we are primarily concerned with means, but can compare them only by virtue of information or assumptions about subgroup variances, it may also be of vital importance.

In detail, the effect of coarseness on subgroup variance will vary greatly with the habit and fabric of the rock, and an a priori treatment of these complicating factors is virtually impossible. The main effect, however, is simply a matter of the *number of grain sections contained in a given measurement area,* and is most readily described by analogy with the simpler case of fragment sampling.

Let us suppose that we could dissociate a hand specimen into a pile of monomineralic grains all of the same size. Instead of sampling the hand specimen with a thin section of some fixed area, we now sample the pile with a scoop of some fixed volume. Other factors being equal, the efficiency of the sampling operation will depend on the number of grains which can be gotten into the scoop at a single pass. If the grains are very small, so that a scoopful contains a very large number of them, it will be an excellent sample. If the grains are large in relation to the scoop, a single sample is necessarily less efficient. It may yield exactly the correct answer; but, however correct, this result is not so reliable as a less correct one based on a larger number of grains. (This may seem paradoxical until it is recalled that in practice we do not know the true value either before or after the test.)

The fineness of the grains continues to operate in our favor until individual grains become so small that we cannot identify them properly by the particular method we have chosen to use. At this point we have an excellent sample which we cannot analyze. If, on the other hand, the grains are so large that only a few of them, or perhaps only one or two, can be gotten into the scoop at a time, the analytical work

becomes simple but aimless, for a single scoopful cannot reflect the composition of the pile with suitable accuracy. When we are satisfied that these lower or upper limits have in fact been reached, we abstain from sampling. For grains of intermediate sizes, however, we want to know how reliable a single-scoop sample is and when we must resort to double, triple, or more extreme repetition of the sampling procedure in order to assure ourselves that results for batches of different grain size will be of comparable reliability.

During the present year a procedure has finally been developed which provides this type of information for the common two-feldspar granites. The work has been in progress for the better part of two years, and a full report is being prepared; the discussion given here is accordingly confined to a summary of the principal results.

1. Variance as a function of coarseness: Last year (Year Book No. 53) analytical results for four different measurement areas in each of two granites were summarized. These were chosen as working standards of fine (Westerly) and coarse (Carnmenellis) two-feldspar granite; a similar set of results has now been obtained for a specimen of the Mount Desert, Maine, granite, which is of intermediate grain. In figure 4 the logarithm of the square root of the average major-mineral variance for each rock is shown as a function of the logarithm of the square root of the measurement area. Open and solid circles represent the observed values, and the lines are graphs of the regression equations calculated from these values. From the graphs or underlying equations the analytical error to which an individual thin-section result is subject can be estimated for any of these specimens at any measurement area in the observed range. The expected qualitative comparisons emerge, and of course a similar study could be made of any specimen of two-feldspar granite. This procedure, however, requires an amount of work sufficient to discourage even the hardiest investigator, particularly since the results are strictly applicable to only *one hand specimen*. What is required is some readily obtained measure of coarseness which will serve as a proxy for $\sqrt{A}$ and eliminate the need for a large number of analyses at each of a series of measurement areas.

2. A measure of coarseness in the granitic fabric: Where grain shapes are simple, grain boundaries are relatively free

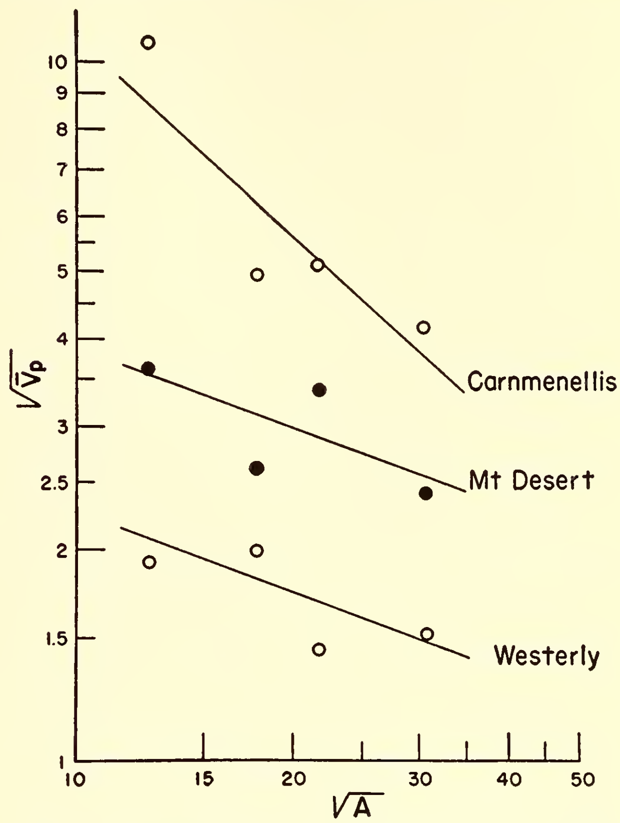

FIG. 4. Regression of analytical error ($\sqrt{V_p}$) on square root of measurement area ($\sqrt{A}$) in three hand specimens of granite.

of re-entrants, and extensive intergrowth of minerals of different species is rare or lacking, several simple measures of grain size are available to the microscopist. In the two-feldspar granites, unfortunately, grain shape is extraordinarily complex, grain boundaries are commonly crenulate and marked by conspicuous re-entrants, and extreme intergrowths are the rule rather than the exception. Despite difficulties in definition and measurement, however, granites do differ in whatever we mean by grain size, and specimens of differing coarseness are usually ranked in

essentially the same order by different observers. Furthermore, as we have just seen, these differences in coarseness influence analytical error in just about the way one would expect; thus, at any particular measurement area in the observed range, the dispersion of results for Westerly, which everyone agrees is extremely fine, is less than that for Mount Desert, which is ordinarily regarded as medium, and considerably less than that for Carnmenellis, which is sometimes called medium coarse, sometimes coarse.

After considerable experimentation a simple procedure has been developed, whose result, to date, appears to characterize the coarseness of the two-feldspar granites with suitable precision. The final datum is an estimate of the number of grain contacts between major minerals per inch (25 mm) of traverse, i.e., the number of times an analyst using a continuous line integrator would change keys because the traverse path crossed from one major mineral to another. Details of the counting procedure will be described elsewhere; it may be noted here that the counting is easily and quickly performed with a ten-key electric adding machine as recorder. A number is assigned each mineral. This number is printed out each time a grain of the appropriate species passes under the cross-hair intersection during the traverse. The result is a paper tape containing a record of the order in which *all* the minerals occur along the line of traverse. From the total, the minor mineral entries together with re-entries of the majors occasioned by the presence of the minors are subtracted; the difference is the I.C. (identity change) number which characterizes the (major mineral) coarseness of the rock. Results obtained to date are shown along the right margin of figure 6, below.

3. Analytical error as a function of coarseness: The I.C. number has been carefully determined for each of the standard specimens, and the next step is to examine the relation between it and analytical error ($\sqrt{V_p}$) for fixed measurement area in these specimens. The I.C. number is a linear frequency, and intuitively one would suppose that its relation to analytical error ought to be very similar to that shown by the square root of the measurement area. This is, at any rate, a consummation devoutly to be desired, and one which does seem to obtain. The abscissae of all points in figure 5 are the I.C. values

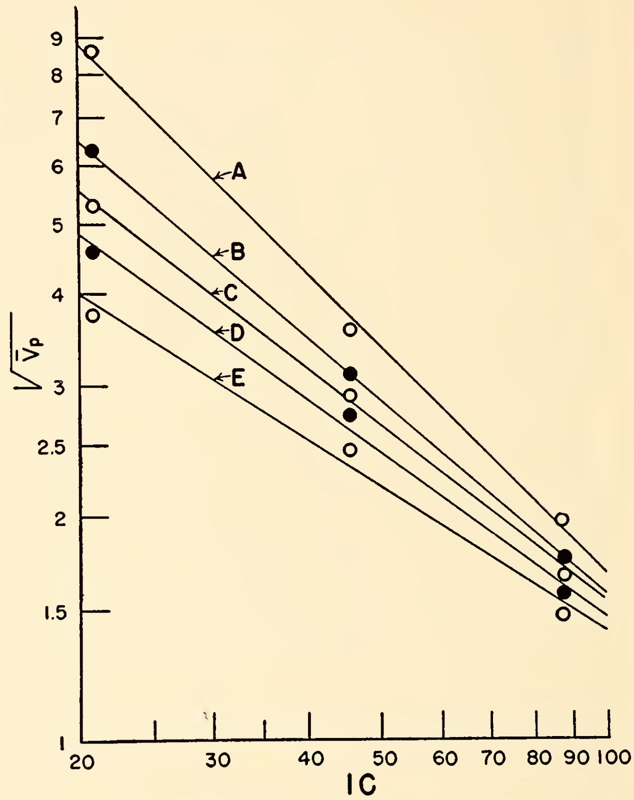

Fig. 5. Regression of analytical error on I.C. numbers for different measurement areas (*A*, 160 mm^2; *B*, 320 mm^2; *C*, 480 mm^2; *D*, 625 mm^2; *E*, 960 mm^2).

for the three standard specimens. The ordinate of each point is the analytical error calculated for a particular measurement area from some one of the regression equations whose graphs are shown in figure 4. The open circle at the lower right corner of the diagram, for instance, is the (estimated) analytical error for a thin section of Westerly with measurement area of 960 mm^2. The open circle at the base of the central cluster gives the same information for Mount Desert; that for Carnmenellis is shown by the open circle at the

base of the left cluster. The line labeled E in the diagram is the graph of the regression equation calculated from these points; from it one may read the predicted value of analytical error, for measurement areas of 960 mm^2, for two-feldspar granites whose coarseness may be characterized by an I.C. number in the observed range. The other lines, developed from the data in exactly the same way, provide the same information for measurement areas of 160 mm^2 (A), 320 mm^2 (B), 480 mm^2 (C), and 625 mm^2 or 1 in^2 (D). It is to be remembered that we are now twice removed from the raw data on variance. The circles of figure 4 are direct experimental values. The circles of figure 5, however, are calculated from the regression lines of figure 4, and the predicted analytical error of which we have been speaking is calculated from new regression lines—those of figure 5—fitted to these adjusted error values. Such a procedure would of course be intolerable unless the fit was good at each step. In fact, it seems to be easily good enough for the purpose at hand; close examination of figure 5 suggests that the departure from linearity at the final stage is quite possibly systematic, but it is so small as to be negligible for practical purposes. Results virtually identical with those about to be described would be reached if the regression equations were abandoned in favor of broken lines directly connecting each outlying circle with the appropriate central one.

4. Controlling analytical error by replication: The quantity $\sqrt{\overline{V}_p}$, the square root of the average major-mineral variance, is essentially the analytical error attaching to a thin-section analysis *as an estimate of the composition of the hand specimen from which the section is cut.*

For each of the lines shown in figure 5 we have an equation of the form

$$\log \sqrt{\overline{V}_p} = a - b \log \text{I.C.}$$

From this it is easy to find how coarse a rock will yield an analysis, based on a single thin section, having an error not larger than any arbitrarily chosen value. One may also readily find critical values of I.C. at which it becomes necessary to run two, three, four, or more thin sections per specimen in order to maintain analytical error at or below the chosen value. Figure 6 gives such a schedule of replication aimed at maintaining analytical error at or below 2 per cent. (It is to be remembered that

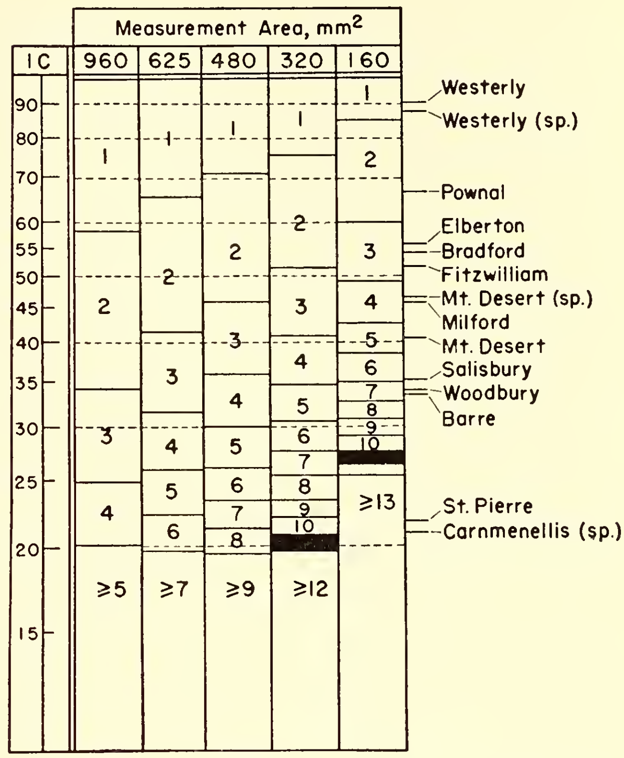

FIG. 6. Number of thin sections per specimen required to maintain analytical error ⩽ 2.0 for different measurement areas and varying coarseness.

this error has the properties of a standard deviation; thus, in the long run one would expect that differences between paired analyses would usually be somewhat less than 3 per cent, and one would view a difference of 6 per cent with considerable suspicion.) The column headings in figure 6 are measurement areas per thin section, the left-hand margin shows a logarithmic I.C. scale, and the digits in the body of the table show the number of slides per specimen required to maintain analytical error at or below 2 per cent. (For analyses based on 1000 to 2000 points, the error arising

from the count alone amounts to about 1 per cent.) Thus, for a rock of I.C. = 30, for instance, three sections of 960 mm^2 will be required, four if only 625 mm^2 are available per slide, and so forth. The *total* area in general becomes smaller, the larger the number of thin sections. Since the same number of points is to be counted in each slide, however, the principal factor of interest to the analyst is the number of slides he must examine.

5. The upper limit of modal analysis: As far as is now known, the limitations imposed by increasing coarseness are entirely practical. They are concerned solely with the amount of work required in order to obtain results sufficiently reliable for the purpose in hand. It will be noted from figure 6, for instance, that the average I.C. number for the granite of St. Pierre, Ille-et-Vilaine, France, is 22. A petrographer obliged to use slides having only 480 mm^2—about ¾ in^2—measurement area would have to analyze seven thin sections per hand specimen in order to maintain analytical error at or below 2 per cent; an analyst using slides of 960 mm^2—about 1½ in^2—measurement area would need only four per specimen. Whether this difference is material is entirely a matter of the question at issue. If all that is needed is a first-class mode for comparison with a chemical analysis of the specimen, neither man is being overworked, and each should, in fact, be willing to do considerably more than the chart demands. If, on the other hand, the objective is a rather detailed reconnaissance in which interest attaches both to the mean composition of the rock and to its point-to-point variation, so that many specimens must be analyzed, the advantage is clearly with the analyst who uses the larger slides. Indeed, he might find such a study entirely feasible, whereas the petrographer using smaller measurement areas would quite properly consider it impractical. Similarly, at any particular measurement area, the same investment of analytical time will yield far more information about a relatively fine rock than about a coarse one. All the rocks for which I.C. numbers are available are shown at the right margin of figure 6; for most of these, detailed analytical results have already been published. Most of the published results are based on only one thin section per specimen, and it is now clear that analytical error, as defined above, accounts for a large part of the total scatter in every case.

6. The lower limit of modal analysis: The upper limit of modal analysis is apparently determined entirely by practical considerations. There is also a lower limit of grain size, below which the method fails. This limit is certainly influenced by practical considerations, but more fundamental factors are also involved. The upper limit is governed essentially by the ratio of grain-section area to measurement area, for it is this that determines the number of grains sampled by a single measurement area. The lower limit, on the other hand, is governed by the ratio of grain diameter (or average length normal to the measurement area) to the thickness of the thin section. It is most readily described for the case of opaque particles in a transparent matrix, the measurements to be performed in transmitted light.

It was long ago pointed out by A. Holmes that in this situation the amount of opaque matter will necessarily be overestimated, for one will always observe an opaque area whose bounds are set by the maximum cross-sectional area of the granule rather than by its true area at the measurement surface.

For spherical particles of uniform radius it may be shown that the bias introduced in this fashion comes to $3k/4r$, where k is the thickness of the thin section and r is the spherical radius (derivation of this relation is contained in a paper now being prepared for publication). If measurements are to be performed in transmitted light—a prerequisite for most of the identifications used in normal petrographic work—the thin-section thickness must be greater than zero. Although very thin sec-

tions can be made, in most laboratories a thickness of 30 microns is standard. Thus the bias given above may be written as $[(3)(30)]/4r=22.5/r$, where r is now in microns. The bias obviously is relatively small if r is of the order of the diameter of opaque granules encountered in most plutonic rocks. In most of these rocks, furthermore, the total amount of opaque material is small, so that, even if the grains were sufficiently spherical to permit application of the appropriate correction, the procedure would hardly be worth while. In the analysis of fine-grained sediments, however, and particularly of those rich in finely divided organic matter, the situation is quite different. If $r=k$, for instance, the observed result is high by 75 per cent; and for r considerably less than k, something not at all uncommon in rocks of this type, the "correction" factor can easily become so large that one would hesitate to use it under any circumstance.

The difficulty arises because the theory of modal analysis requires that areas be measured on a surface, and if one of the constituents is opaque this surface cannot be located with sufficient accuracy. But similar difficulty may also be encountered in the absence of opaque material. Most of the members of a swarm of albite stringers in a grain of perthite, for instance, may be below the surface of the thin section, yet all may show the appropriate refringence and birefringence. They are all albite, but only those which actually intersect the surface should be recorded in the analysis. A finite thickness is indispensable in making the identifications, but the measurement is only of the surface. When the intersections of grain sections with the surface cannot be suitably located, the lower limit of modal analysis has been reached. This limit will vary with the optical properties, form, and habit of the minerals involved. There is room for a careful experimental study of the problem; such a study would appear to be almost a prerequisite in the establishment of reliable analytical techniques for the fine-grained sediments and partially glassy volcanic rocks.

PALEOBIOCHEMISTRY

Organic constituents of fossils (Abelson). The organic constituents of the earth's crust provide the key to the answer to many important questions and raise others. Some of these are of great philosophic interest, such as: What was the origin of life? What can be said about the nature of biochemical processes of extinct animals? Other questions have important practical facets: What is the origin or origins of petroleum? What are the chemical processes involved in the formation of coal?

The research program of the past year in paleobiochemistry has been aimed at providing information which may help in answering some of these great questions. Central to all these problems is the behavior of organic substances in geological environments.

For this purpose it was illuminating to study the fate of organic matter incorporated in shells and bones. The clam shell from *Mya myarenaria* was employed to check the effect of relatively short exposures to geological environments. Through the courtesy of Wilmot Bradley, recent specimens of this shell and items dated by Lawrence Kulp at 1000 years could be compared. Solution of the recent shell in dilute hydrochloric acid left a residue of filamentous light-colored protein. The 1000-year-old specimen yielded protein which was amber-colored and had only a relatively limited mechanical strength. Tests were made to determine total protein content and comparative amino acid analysis. Results were identical on the two types of specimen.

In another experiment, shells were dissolved in a mixture of dilute hydrochloric acid and trichloracetic acid. Insoluble pro-

tein was removed from the mixture by centrifugation. The clear supernatant solution was examined as to its content of free amino acids, peptides, or soluble protein. A negligible amount was found in each case, a fact which shows that the proteins of the 1000-year-old shell had not been broken into fragments of low molecular weight.

For studying older materials the clam *Mercenaria mercenaria* was a convenient object. This edible hard-shell clam, which lives today, is represented by fossil specimens dating back 30,000,000 years. Specimens of Pleistocene age were made available by Wendell Woodring. These were originally collected at Wales Bluff, Virginia, and on geologic evidence are thought to be in the range 100,000 to 1,000,000 years old. Comparison of recent and older specimens showed that marked changes had occurred in the fossil proteins. The material isolated by the usual protein precipitants was a black, tarry substance which could scarcely be called a protein, although it yielded amino acids on hydrolysis. Examination of the clear supernatant solution revealed that it contained peptides and free amino acids. The total amino acid content of the Pleistocene shell was only 18 per cent of that found in recent shells.

When Miocene (30,000,000-year-old) shells were examined, amino acids were found, but no traces of proteins or peptides could be detected. These results are summarized in table 1.

A picture emerges. Initially most of the protein of the shell is present in water-insoluble layers. For thousands of years only moderate changes occur, which do not affect the solubility of the protein. By the time 1 to 5 per cent of the peptide bonds are broken (10,000 to 100,000 years), the protein fragments are much more soluble and some can be leached out of the shell. Some of the amino acids or peptides are probably entrapped in the aragonite structure. Ultimately in the presence of water these peptide bonds are broken, leaving only free amino acids in the shell. It is of interest to note in table 1 that the free amino acid content of the shell changed only moderately in the period from 1,000,000 to 30,000,000 years.

Examination of bones from the La Brea tar pit in Los Angeles yielded an interesting result. These fossils were preserved in an asphalt matrix for perhaps 100,000 years. Total amino acid content of several specimens of bone was 10 to 12 per cent. Studies of the peptide linkage showed that there were virtually no free amino acids and that the amino acids remained linked together. Undoubtedly the asphalt had several protective functions. It provided an essentially sterile, anaerobic environment in which the concentration of water was very low.

TABLE 1

AMINO ACID CONTENT OF *Mercenaria mercenaria*

Age	Amino acid content (μmol/g)		
	Protein bound	Soluble protein or peptide	Free
Recent	33.0	1.5	<0.35
Pleistocene	2.1	2.25	1.0
Miocene	0	0	0.75

The results from these studies have significance in two areas: (*a*) Pleistocene dating and (*b*) theories of the origin of life.

Dating by C[14] methods is limited by the 5300-year half life of this isotope. Under favorable conditions specimens as old as 40,000 years may be measured. On the other hand, uranium-lead and rubidium-strontium time clocks are not suitable for times as short as 1,000,000 years. There is thus a very important period which cannot be accurately dated. In this period the culminating evolution of man occurred, and the great ice ages, whose dates should be better known to establish a possible pattern of recurrence. The time rate of degradation of proteins in fossils could, in prin-

ciple, provide a dating method. This method could not have the accuracy of the schemes based on radioactivity, but might nevertheless be useful. It would be particularly interesting to correlate isotopic measurements on shells with such dating. From this could come a measure of the temperature of the marine environment at the time of formation of the shells.

Studies of the stability of organic substances are of particular interest to those concerned with possible mechanisms of the origin of life. Recent studies by Miller and Fox have demonstrated two methods by which some of the key amino acid building blocks could be synthesized under terrestrial conditions by nonvital processes. Synthesis of peptides by nonbiological means has also been demonstrated. One can therefore visualize a primitive environment in which amino acids and peptides were present. Rate of degradation is the factor limiting the ultimate concentration of these key substances. Work at the Geophysical Laboratory has demonstrated that most of the amino acids are sufficiently stable to endure for millions of years at moderate temperatures. The new results on proteins show that peptide bonds may endure for as much as a million years even in a moist environment. Under special conditions where water is not present, peptides would probably be stable for even longer periods.

RADIOACTIVITY

Low-background counting (Libby, Abelson). Naturally occurring radioactive substances provide the key to many geochemical and geophysical problems. C^{14} dating of carbon-containing materials is a typical example of the kind of problem that may be approached. Tritium has many applications in meteorological and ground-water investigations. Recent work elsewhere has demonstrated that other light-radioactive substances are produced through action of cosmic rays.

Measurement of these substances is not easy, since intensities are low and radiations emitted are usually easily absorbed. Special equipment permitting high counting efficiency and low background, originally developed at the University of Chicago, has now been installed at the Geophysical Laboratory. One use for this equipment is in the study of reaction rates. Reactions involving C^{14}-tagged compounds can be studied even if the time required for the process to proceed halfway is as long as 10,000 years. Conway at the University of Chicago has been studying the thermal degradation of alanine. The stability of some of the organic constituents of fossils, petroleum, shale, and coal can now be determined at the Geophysical Laboratory.

"Hot atom" chemistry (Libby, Abelson). Nuclear reactions often lead to the formation of radioactive isotopes, and usually the newly formed nucleon has a considerable amount of kinetic energy. In some cases this may amount to 20,000 electron volts, a value far in excess of chemical binding energies. These newly formed isotopes are accordingly called "hot atoms."

If a substance such as alanine ($C_3H_7NO_2$) is exposed to neutrons in a nuclear reactor, some of the nitrogen is converted to C^{14}. The newly formed atom travels for a short period at high velocity in the neighboring alanine molecules. Its ultimate fate is not at present predictable. Some experiments have been carried out at the Geophysical Laboratory to study this problem. Alanine was irradiated with neutrons at the Argonne National Laboratory. The alanine was dissolved in water and repeatedly recrystallized from an alcohol-water mixture. After six crystallizations, specific activity of the product reached a constant value. It was determined that 8 per cent of the hot C^{14} atoms came to rest as part of alanine molecules, apparently as a result of a billiard-ball-type collision in which C^{14} replaced one of the carbon atoms.

PHOSPHATE CHEMISTRY

The system $NaPO_3$—$Na_4P_2O_7$—$K_4P_2O_7$—KPO_3 (Morey, Boyd, England, Chen). Silicates and phosphates have a fundamental similarity in their propensity for forming extended structures called polymers. In each case the structural element is a tetrahedral grouping of four oxygen atoms around a central positive ion: in the one case, a silicon atom, in the other, a phosphorus atom. In each case these characteristic tetrahedral groups have a strong tendency to polymerize, that is, to join with adjacent tetrahedral groups by sharing oxygen atoms to form polymers. These polymers may be closed rings, extended networks, or long-chained linear polymers. In silicate and phosphate melts, both of which are viscous because of their polymerized structure, the rearrangement of these usually twisted chains or networks to form crystals often requires special heat treatment; such melts are easily cooled to form glass. In the system Na_2O—P_2O_5 the glass-forming tendency extends over a greater molecular composition range than in the system Na_2O—SiO_2.

The modern classification of silicate minerals is based on the polymers formed. In some cases these are not polymers, but monomers; in other cases they are ring polymers, as in beryl; in still other cases, chain polymers of indeterminate length, as in the pyroxenes and amphiboles. The mineral structures are deduced from X rays, but they cannot be studied in water solution because of the insolubility of the silicates. In solutions of the soluble sodium and potassium silicates, reaction with water with formation of monomeric forms takes place so rapidly that the suspected presence of polymers has not been proved. But in the soluble phosphates, such as those in the system $NaPO_3$—$Na_4P_2O_7$—$K_4P_2O_7$—KPO_3, the polymerized structures are so persistent at ordinary temperatures that solutions of the same composition may have different properties. Thus a water solution in which the $Na_2O:P_2O_5$ ratio is 1:1, made either from the monomer NaH_2PO_4 or from H_3PO_4 and NaOH, has no power to soften water and on evaporation yields crystals of $NaH_2PO_4 \cdot 2H_2O$. A solution of the same composition but made from crystalline $NaPO_3$ I, a ring polymer, also has no power to soften water and on evaporation yields crystals of $NaPO_3 \cdot 2H_2O$. If the solution is made from glassy $NaPO_3$, a long-chain linear polymer, it is an excellent water softener, and on evaporation yields a horny, amorphous mass.

The sodium phosphates which are included in this study have important industrial applications. Since the basic discovery by Hall of its property of softening water, the glassy sodium metaphosphate, sold as Calgon or under some other trade name, has found extensive application. It is a linear polymer of indeterminate chain length, and softens by a process known as "sequestering," which probably means that the calcium ions in hard water get tangled up in the long phosphate chains and thus are removed from solution. In recent years enormous and increasing quantities of the linear polymer sodium tripolyphosphate, $Na_5P_3O_{10}$, a compound on the side $NaPO_3$—$Na_4P_2O_7$ (see fig. 7), have been incorporated into synthetic detergents such as Tide, both because of the sequestering effect of its long phosphate chains and because of its effective but controlled alkalinity. The compound tetrasodium pyrophosphate, $Na_4P_2O_7$, also is a chain polymer, somewhat more alkaline than the tripolyphosphate, and hence finds wide application as an industrial detergent. In contrast, the potassium phosphates have few industrial applications. They have a limited use as detergents and sequestering agents, and potassium pyrophosphate is used to meet special problems in high-temperature and high-pressure boilers as a water conditioner.

The system $NaPO_3$—$Na_4P_2O_7$—$K_4P_2O_7$—KPO_3 is part of the ternary system Na_2O

—K_2O—P_2O_5, and the phase equilibrium diagram of figure 7 may be regarded as a section of the triangular diagram Na_2O—K_2O—P_2O_5, in which the base angles have been changed from 60° to 90°. The side $Na_4P_2O_7$—$K_4P_2O_7$ of this figure is the only side not discussed in previous publications. These two compounds form a complete series of solid solutions with a minimum melting point. The melting-point surface in the field of these pyrophosphate solid solutions is concave upward, with its minimum temperature a broad valley and with sides of decreasing slope as it sweeps downward to its intersection with the field of the tripolyphosphates, along the boundary curve N_2ABK_2. Both sodium and potassium tripolyphosphate melt with decomposition, and so do all intermediate mixtures; hence the pyrophosphate surface extends over the tripolyphosphate join.

The crystalline tripolyphosphates can exist only below their temperatures of incongruent melting. They are sodium tripolyphosphate, $Na_5P_3O_{10}$; potassium tripolyphosphate, $K_5P_3O_{10}$; and a binary compound, $Na_5P_3O_{10} \cdot K_5P_3O_{10}$. There is extensive solid solution along this join. The melting surface of $Na_5P_3O_{10} \cdot K_5P_3O_{10}$ is convex upward; hence its intersection with the melting surface of the pyrophosphate solid solutions, which is concave upward, gives rise to a broad plateau of small temperature gradient. The melting surfaces of the tripolyphosphate compounds are less steep than any others in this system, and are terminated by their intersections with the melting surfaces of the

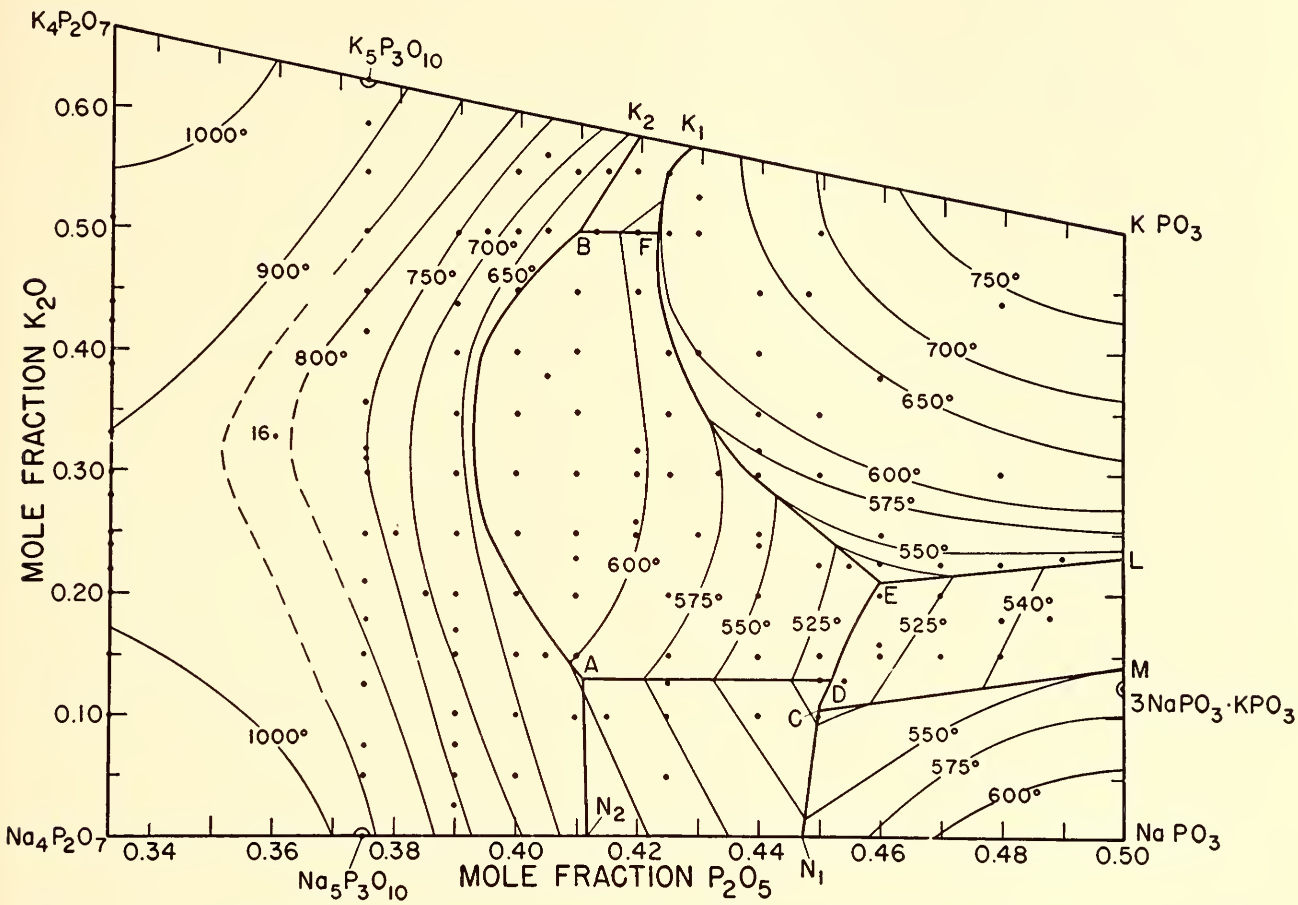

FIG. 7. The system $NaPO_3$—$Na_4P_2O_7$—$K_4P_2O_7$—KPO_3. This diagram may be regarded as a section of the triangular diagram Na_2O—K_2O—P_2O_5 in which the angle at the base is changed from 60° to 90°. The field of pyrophosphate solid solutions extends to the boundary N_2ABK_2; that of $Na_5P_3O_{10}$ is the area N_1N_2AD; that of $Na_5P_3O_{10} \cdot K_5P_3O_{10}$, the area $ABFED$; that of $K_5P_3O_{10}$, the area FBK_2K_1; that of $NaPO_3$, the area $NaPO_3$—N_1CM; that of $3NaPO_3 \cdot KPO_3$, the area $MCEL$; and that of KPO_3, the area KPO_3—$LEFK_1$.

metaphosphate compounds, along the boundary curves N_1C, CD, DE, EF, and FK_1. The lowest melting temperature, 512° C, is at the ternary eutectic, E.

DISTRIBUTION OF TRACE ELEMENTS

The distribution of trace elements between coexisting minerals in a rock reflects the conditions under which the rock formed. Data obtained by analysis of the various minerals of the rock, however, can be interpreted only if the influence of such variables as temperature, pressure, and extent of equilibrium or disequilibrium is known.

A study was begun last year with the aim of furnishing some of the most urgently needed fundamental data. Since then a systematic investigation of the effects of cesium and thallium on the system $K_2O \cdot Al_2O_3 \cdot 6SiO_2$—$H_2O$ at different temperatures and pressures has been carried out. A large range of compositions and a variety of growth conditions were investigated. Special radioactive tracer techniques were developed for work in the microgram region. The results which have been obtained are very helpful in illuminating the behavior and occurrence of trace elements in nature.

The cesium-potassium equilibrium in the system sanidine—water (Eugster). The cesium-potassium equilibrium in the system $(Cs,K)AlSi_3O_8$—H_2O (sanidine—water) was studied by synthesizing cesium-bearing sanidine in a hydrothermal environment. Sanidine was grown from a fluid phase with a fixed Cs/K ratio. After crystallization was completed, the sanidine was examined optically and with X rays, and its potassium and cesium contents were measured. The concentration of cesium in the sanidine was determined by radioactive assay. The potassium content was calculated from the weight of the total sample. Reproducibility of the results was tested by repeating each experiment. The differences between two runs were 5 per cent or less when all factors of synthesis and analysis were kept strictly constant. The distribution factor F (defined as the ratio Cs/K in sanidine over Cs/K in the fluid phase) was calculated from the Cs/K ratio of the fluid and the cesium and potassium content of the sanidine.

A summary of the results of experiments under equilibrium conditions is given in table 2. Only the region in which the Cs/K ratio in the sanidine is directly proportional to the Cs/K ratio in the fluid phase has been studied. This region lies well below the limit of solid solution of cesium in sanidine for all temperatures investigated (400° to 800° C). Compositions ranging from Cs/K=0.0002 to Cs/K=0.01 have been studied at 1000 and 2000 bars water vapor pressure.

TABLE 2

REVISED DISTRIBUTION FACTOR F FOR THE PAIR Cs/K BETWEEN SANIDINE AND ITS HYDROUS VAPOR

$$F_{(T)} = \frac{\text{Cs/K in sanidine}}{\text{Cs/K in vapor}}$$

Temperature (°C)	F
800	1.20
700	0.96
600	0.70
500	0.48

Determined at 1000 and 2000 bars water vapor pressure.

From the results the following conclusions can be drawn. Cesium enters the sanidine lattice much more readily at high than at low temperatures. At about 700° C the cesium content of the feldspar is equal to that of the fluid phase in equilibrium with it. At 800° C the feldspar growing from a fluid phase of the same composition will be richer in cesium than the fluid phase by a factor of 1.2:1; whereas at 500° C it will be poorer by a factor of 1:4. The temperature dependence of this fractionation is much greater than was previously suspected. No difference between

the results from experiments performed at 1000 and at 2000 bars could be detected. The pressure influence, therefore, must be smaller than the experimental error (± 5 per cent of the Cs/K ratio in sanidine). It is well known that cesium is greatly enriched in feldspars and micas of moderate- to low-temperature hydrothermal origin. The enrichment over the average value for the earth's crust can be as large as 1000-fold. Different causes can be responsible for this enrichment. In the temperature region in which pegmatites and hydrothermal deposits are thought to form, the distribution factor F for cesium between feldspar and solution is substantially smaller than 1, according to the experiments. If, during the crystallization of the hydrothermal solution in a closed system, fractionation between solids and liquid takes place, then the concentration of cesium in the remaining solution will increase markedly as crystallization proceeds. The Cs/K ratio in a feldspar at a particular moment in the fractional crystallization process is given by the relation

$$\left(\frac{\mathrm{Cs}}{\mathrm{K}}\right)_S = F_{(T)}\left(\frac{\mathrm{Cs}}{\mathrm{K}}\right)_O (1-S)^{F_{(T)}-1},$$

where $(\mathrm{Cs/K})_S$ is the Cs/K ratio in the feldspar; $(\mathrm{Cs/K})_O$ is the original Cs/K ratio in the liquid; $F_{(T)}$ is the distribution factor, given as

$$\frac{\text{Cs/K in solid}}{\text{Cs/K in liquid}}$$

at temperature T; S is the fraction of the original liquid which has already crystallized. (McFee; Holland and Kulp; Neumann, Mead, and Vitaliano.) It is evident from this equation that the Cs/K ratio of the sanidine, which will crystallize last, will be much larger than the original Cs/K ratio of the liquid, if the distribution factor F for the temperature interval of crystallization is significantly smaller than 1. If during crystallization no fractionation between liquid and crystals takes place and the feldspars adjust their composition continuously to the changing conditions, then after crystallization has been terminated all feldspars will show the same Cs/K ratio, which in turn is equal to the Cs/K ratio of the original solution.

The increase in proportion of cesium in a given feldspar depends on two conditions; namely, the temperature of crystallization and the degree of fractionation between solids and liquid. The temperature influence has been determined in the laboratory, and we can now attempt to interpret the distribution of cesium in feldspars of a specific rock mass and thereby trace the path of crystallization and evaluate the amount of fractionation, resorption, and interaction with the country rock that has taken place.

It should be pointed out that this process of enrichment by fractional crystallization is not dependent on the origin of the liquid or fluid phase. It holds for solutions of magmatic as well as metasomatic origin. The only requirement is that the solution crystallize within a confined volume. Solutions can also be enriched in cesium by dissolving cesium, preferentially from feldspars of the country rock, at temperatures at which the distribution factor F is smaller than 1. A solution formed by this process can show a Cs/K ratio several times as large as that of the original feldspars. If the volume of a pegmatite crystallizing from this solution is small as compared with that of the country rock in which the solution was saturated, then the original Cs/K ratio of the feldspars in the country rock will be unaffected and the Cs/K ratio of the feldspars in the pegmatite will be considerably larger. The extent of this increase is solely dependent on the temperature of crystallization of the pegmatite, and the increase is inversely proportional to the F value for this temperature. Fractional crystallization can enhance this enrichment still further for feldspars crystallizing at a late stage.

The thallium-potassium equilibrium in the system sanidine—water (Hopson, Eugster). Preliminary results on the Tl-K frac-

tionation between sanidine and a hydrous fluid phase are now available. As in the case of cesium, the distribution factor

$$F=\frac{\text{Tl/K in sanidine}}{\text{Tl/K in fluid phase}}$$

is temperature-dependent. More thallium will enter sanidine crystallizing from a fluid phase with a given Tl/K ratio at high temperatures than at low temperatures. But this temperature dependence is much less pronounced than in the case of cesium. This result can well be explained on the basis of the ionic properties of the elements involved. The ionic radii of thallium (1.47 Å) and potassium (1.33 Å) are much closer than those of cesium (1.67 Å) and potassium. The greater geochemical coherence of the pair K-Tl is well known from analysis of natural mineral assemblages.

Deuterium fractionation (Boyd). A joint project has recently been set up with Irving Friedman, of the U. S. Geological Survey, for the purpose of studying, under controlled conditions, the fractionation of the hydrogen isotope deuterium in geologically important systems. The objectives of this project are broad. It is proposed to investigate the fractionation of deuterium between various hydrous silicates and water vapor with which they are in equilibrium. An investigation of deuterium fractionation between water in the vapor phase and water in solution in melts and glasses will also be undertaken.

Possible applications are many. A considerable quantity of data has been obtained concerning the fractionation of deuterium in natural minerals and glasses. Data obtained from the synthetic studies will be of great aid in interpreting the processes by which the natural phases have been produced. Distribution coefficients obtained may prove valuable as geologic thermometers. There exists further the possibility of distinguishing juvenile from meteoric water in rocks and natural glasses.

Runs made to date have been mostly with the aluminous amphibole pargasite, whose stability relations are discussed in another section of this report. The pargasite is grown at high temperature and pressure in the presence of water vapor. Both the vapor and the combined water in the pargasite are then analyzed for their deuterium content with a mass spectrometer.

Considerable difficulty has been encountered in initial runs because of a progressive shift in the composition of the vapor phase. This shift is produced by reaction of water in the vapor phase with the bomb wall. Free hydrogen is generated by this reaction. The deuterium fractionation between H_2 and H_2O is such that the H_2O becomes progressively heavier as H_2 forms and diffuses out of the system. Although the run is sealed in a welded platinum capsule, the water within the capsule shifts in sympathy with the surrounding water, owing to hydrogen exchange through the platinum. This difficulty has been greatly reduced, although not completely eliminated, by packing the capsules in CuO, which acts to keep the H_2 pressure down.

In the majority of the runs made thus far, the pargasite has been found to be close to 2 per cent richer in deuterium than the associated vapor, irrespective of the shift in vapor composition. This is an expected and reasonable result, but more runs will have to be made before it can be established that it is an equilibrium result.

Some runs have also been made with talc. These runs have not yielded usable results, however, because it has not been possible with talc to get a clean separation of water in the vapor phase and water combined in the silicate structure.

MAJOR MINERAL GROUPS

One of the principal aims of modern petrologic research is to develop an understanding of the varieties of mineral assemblages that occur in nature. The mineral assemblage that one finds in a particular rock is wholly a function of the bulk

chemistry of the rock and of the physical conditions under which it formed. A laboratory worker active in this field of research tries, in his experiments at high temperature and pressure, to duplicate natural mineral assemblages under controlled physical conditions. Having succeeded in this attempt, he is then in a position to interpret natural assemblages in terms of known mineral compatibilities and incompatibilities and to specify, in so far as the observed phase relations make it possible, the physical conditions under which the natural assemblages formed.

The aim of the laboratory worker is, thus, primarily to offer physical-chemical interpretations of the observations of the field petrologist. The contribution of laboratory research may, however, extend farther than this. Most minerals are not chemical compounds of fixed composition, but are subject to wide variations in their chemical constitution. Adequate description of a mineral assemblage, therefore, requires knowledge of the precise composition of the minerals involved. This knowledge is most conveniently acquired by measuring a group of optical or X-ray parameters, or both, which are in turn related to the chemical composition. In mineral groups of complex chemistry the relation of physical parameters to chemical composition can often be successfully carried out only on groups of synthetic minerals of controlled composition.

Amphiboles

The amphiboles are a good illustration of the situation just described. Although they form one of the major building blocks of igneous and metamorphic rocks, the chemistry of the amphibole group as a whole, and the manner in which the composition of a particular amphibole reflects the chemical and physical environment in which it formed, are as yet poorly understood. The reason for this lack of understanding will be evident when it is realized that all eight of the elements which together make up 99 per cent of the earth's crust are important constituents of common amphiboles.

Natural amphiboles lend themselves to division into three groups: the calciferous amphiboles, the alkali amphiboles, and the anthophyllite-cummingtonite group. Some solid solution exists between these groups, particularly between the alkali and the calciferous amphiboles, and there is a wide range of solid solution within each group. The extensive solid-solution relations among amphiboles have led to great confusion in the nomenclature. In the discussion which follows, the pure "end members" worked with in the laboratory are each given the name of that natural amphibole whose composition they most closely approximate. It must be understood that, for example, natural glaucophanes do not have exactly the composition $Na_2Mg_3Al_2Si_8O_{22}(OH)_2$. Similarly, the type formulas for the three groups described below include only the principal or singular substitutions in a group, and not all possible substitutions.

The amphibole group whose members are most abundant in common igneous and metamorphic rocks is called the calciferous amphibole group. The type chemical formula for a calciferous amphibole can be written: $(Na,K)Ca_2(Mg,Fe,Al)_5(Si,Al)_8O_{22}(OH)_2$. Such amphiboles are found in a wide variety of metamorphic rocks, ranging from those that are little changed from the original sediments and volcanic rocks from which they formed to those that have been buried deep in the earth's crust and subjected to high temperatures and pressures. Calciferous amphiboles are, as well, common constituents of lavas, in which they have grown as crystals in equilibrium with silicate melts of various compositions.

A second amphibole group, which is simpler chemically than the calciferous amphiboles, is the anthophyllite-cummingtonite group. The type formula for this group is $(Mg,Fe,Al)_7(Si,Al)_8O_{22}(OH)_2$. These amphiboles are found most commonly in metamorphosed ultramafic rocks and iron formations.

The third group comprises the alkali amphiboles, whose type formula is $(Na,K)_2$-$(Mg,Fe,Al)_5Si_8O_{22}(OH)_2$. The alkali amphiboles are found in soda-rich igneous rocks and in certain metamorphic rocks suspected of forming under conditions of very high pressure.

Laboratory phase-equilibrium investigations have been undertaken in all three of these amphibole groups.

Calciferous amphiboles (Boyd). The first step in a study designed to determine the phase relations in systems containing hydrous minerals is to work out the pressure and temperature conditions under which the various individual minerals are by themselves stable. Such studies are now nearly complete for two common calciferous amphiboles, tremolite and pargasite.

At the time of last year's report, a stability field had been worked out for tremolite ($Ca_2Mg_5Si_8O_{22}(OH)_2$) on the basis of the crystallization or noncrystallization of tremolite from glass and oxide mixtures of tremolite composition. It has since been found possible to reverse the tremolite breakdown reaction on long runs; that is, to grow tremolite from its high-temperature breakdown products, enstatite, diopside, and quartz. The amount of tremolite so obtained is not large, but it can be detected readily with the microscope. The reversibility of this reaction proves that the relations found for tremolite represent true stability.

The stability studies on tremolite have been extended to pressures up to 2000 bars at a temperature of 900° C. The tremolite yield at this pressure is very much better than at 1000 bars and less. The reaction to form tremolite is always, however, very sluggish, and has been a problem for this reason.

The calciferous pargasite has, along with tremolite, been selected for detailed study. The formula for pargasite is $NaCa_2Mg_4$-$AlAl_2Si_6O_{22}(OH)_2$. It occurs naturally in nearly pure form in metamorphosed dolomitic rocks. Pargasite is chemically very similar to the average igneous or high-grade metamorphic hornblende. The principal difference between common hornblende and pargasite is that the former contains some iron in the magnesium position.

Pargasite has proved much easier to synthesize than tremolite. It is possible, in a suitable pressure-temperature range, to make an oxide–sodium disilicate mix react virtually completely to pargasite in a few days. The X-ray pattern of synthetic pargasite is shown in figure 8. An X-ray pattern of natural pargasite from the type locality at Pargas, Finland, is included for comparison.

The composition of pargasite falls in a six-component system, and the breakdown relations are correspondingly complex. The breakdown products of pargasite are aluminous diopside + nepheline + forsterite + anorthite + spinel + water. Diopside, forsterite, and nepheline dominate the X-ray pattern of the breakdown products, but characteristic lines of anorthite and spinel can be distinguished. A detailed X-ray study of the join diopside ($CaMg$-Si_2O_6)—corundum (Al_2O_3), designed to permit estimate of the amount of alumina in solution in the diopside, is now under way.

The addition of soda and alumina to tremolite to form pargasite increases the stability range of the amphibole. At 1000 bars water vapor pressure, tremolite is stable up to 935° C, but at that same pressure pargasite is stable up to 1050° C. The high temperatures of these amphibole breakdown reactions are in accord with the occurrence of amphiboles as phenocrysts in lavas and their persistence to a high grade of regional metamorphism. The higher stability range of pargasite relative to that of tremolite may reflect the tendency of natural amphiboles to take up soda and alumina during pro-grade metamorphism.

On long runs it has proved possible to grow both tremolite and pargasite coarse enough to obtain good optical data. The optical properties of synthetic tremolite and

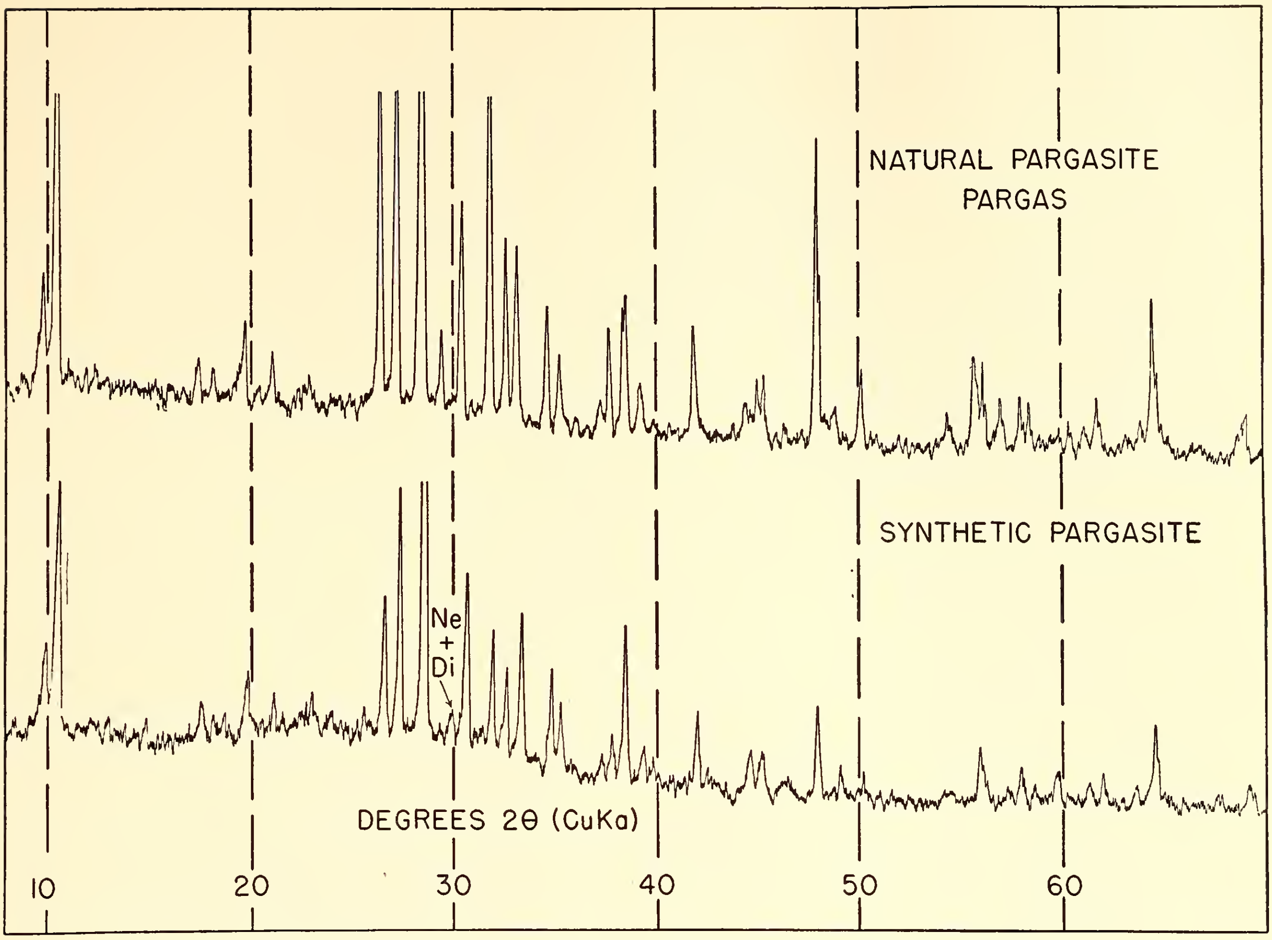

FIG. 8. X-ray diffraction patterns of synthetic and natural pargasite

synthetic pargasite are listed in table 3. The indices were measured by the usual immersion method. The optic angles and extinction angles were measured by J. R. Smith with a universal stage. Winchell's extrapolated values for the natural end members are included for comparison.

The anthophyllite-cummingtonite group (Boyd). An investigation of the anthophyllite-cummingtonite group of amphiboles has been carried out at 1000 bars water vapor pressure. Two amphibole solid solutions, the monoclinic cummingtonite series and the orthorhombic anthophyllites, can be expressed by the formula $Mg_7Si_8O_{22}(OH)_2$—$Fe_7Si_8O_{22}(OH)_2$. These amphiboles break down to orthorhombic pyroxenes, the hypersthene series.

Both the orthorhombic and the monoclinic amphiboles were synthesized in the course of the investigation. These phases grow readily, particularly in compositions rich in iron. They yield by far the most coarsely crystalline products obtained in any amphibole system thus far investigated. Toward the magnesian end of the

TABLE 3

OPTICAL PROPERTIES OF NATURAL AND SYNTHETIC AMPHIBOLES

	n_z	n_x	$2V$	$z\Lambda c$
Synthetic tremolite	1.625	1.601	−73°±1°	16°±2°
Tremolite (Winchell)	1.628	1.598	−88°	18°
Synthetic pargasite	1.645	1.624	+74°±4°	21°±2°
Pargasite (Winchell)	1.64	1.62	+85°	28°

system the amphiboles crystallize as stubby needles; as more iron is added, the amphiboles become progressively more fibrous. In the composition range $Mg_{40}Fe_{60}$ to $Mg_{50}Fe_{50}$, the anthophyllites are truly asbestiform, and a run in which they have formed consists of a mat of tiny fibers. This fact may be of interest to those engaged in the development of synthetic asbestos.

Cummingtonites were obtained in a few runs in the composition range $Mg_{85}Fe_{15}$ to $Mg_{70}Fe_{30}$. A monoclinic amphibole more magnesian than $Mg_{85}Fe_{15}$ could not be synthesized. This relation is in harmony with the evidence obtained from naturally occurring phases in this system. The pure magnesian monoclinic amphibole has not been found in nature. Cummingtonite was synthesized only at temperatures above 800° C, close to the apparent breakdown interval. Orthorhombic anthophyllites were produced in the same composition range at lower temperatures.

Runs in which these amphiboles were produced nearly always contained some hypersthene. In all cases the hypersthene was richer in iron than the associated amphibole—an observation in agreement with the slope of the apparent breakdown interval toward the iron end of the system.

No amphiboles were produced whose compositions were more iron-rich than $Mg_{50}Fe_{50}$. Bulk compositions richer in iron than this ratio yielded in all cases amphiboles of a composition close to $Mg_{50}Fe_{50}$, fayalite whose composition was found by X ray to be $Fo_{30}Fa_{70}$, and quartz. This same relation persists into the hypersthene field. The most iron-rich hypersthene encountered was $En_{58}Fs_{42}$. Compositions richer in iron yielded, above the apparent amphibole breakdown, hypersthene of this composition, fayalite whose composition was found to be always near $Fo_{25}Fa_{75}$, and quartz. These phase relations, involving hypersthene and fayalite, represent a large shift from those encountered in the investigation of the system $FeSiO_3$—$MgSiO_3$ at 1 atm.

The amphibole relations encountered in this investigation seem, in some respects, to clarify and to be consistent with the assemblages found in rocks. In other respects the experimental data reviewed are at variance with natural systems, particularly in the apparent absence of a stability field for iron-rich cummingtonites. There is, moreover, considerable uncertainty, from an experimental viewpoint, as to the true stability of the phase assemblages which have been encountered. It appears certain that the magnesian amphibole end member, anthophyllite, is metastable in the temperature-pressure range in which it has been synthesized. It can be grown from a mixture of magnesia and silica in a temperature interval of about 50° above the breakdown temperature of talc at 1000 bars. The anthophyllite will persist in such an environment for as long as a week, but in runs of more than a week it will break down to enstatite and quartz. The iron-rich amphiboles in this system have not shown this tendency; they have been synthesized on runs of as long as three weeks. Nevertheless, attempts to reverse the breakdown reaction, i.e. to crystallize the amphiboles from hypersthene and quartz, have not been successful. The phase relations encountered may, therefore, not be accepted with confidence as indicating true stability ranges.

Alkali amphiboles (Boyd). Reconnaissance runs have been made on two important alkali amphiboles, magnesian riebeckite $[Na_2Mg_3Fe_2'''Si_8O_{22}(OH)_2]$ and glaucophane $[Na_2Mg_3Al_2Si_8O_{22}(OH)_2]$. Riebeckite is found in nature predominantly in sodic igneous rocks. Glaucophane is the amphibole equivalent of the pyroxene jadeite. Particular interest surrounds glaucophane inasmuch as, like jadeite, it is believed to indicate a high-pressure environment. These two amphiboles differ chemically only in the exchange relation between ferric iron and aluminum in sixfold co-ordination.

Runs made on glaucophane composition at temperatures ranging from 750° to

825° C and pressures of 500 to 1000 bars have in all cases yielded mixtures of amphibole and albite. The amphibole formed in these runs has indices, an X-ray pattern, and an extinction angle close to those of natural glaucophane. A general experience in attempting syntheses of amphiboles has been to obtain the desired amphiboles with metastable assemblages of breakdown products. In the present case, however, there is no sign of forsterite and enstatite, which, with albite, would be the expected breakdown products of glaucophane. It is therefore apparent that the amphibole crystallized from a glaucophane composition is not "on composition"; i.e., it is poorer in soda and alumina than true glaucophane. In a run at 850° and 1000 bars a glaucophane mix melted to forsterite and liquid. Runs on glaucophane are being extended to higher pressures.

Runs made on magnesian riebeckite composition at temperatures ranging from 750° to 850° C and pressures from 500 to 1000 bars have in all cases crystallized to amphibole together with a small amount of quartz. The amphibole has an X-ray pattern very similar to that of natural riebeckite. The amphibole made in these runs has a variable index of refraction, indicating that some iron was lost in solution in the platinum capsule. Further experimental work on riebeckite will therefore necessitate iron analysis of the phases produced.

Plagioclase Feldspars

Plagioclase feldspars are major constituents of all the common igneous rock types, which have been estimated to make up more than 90 per cent of the volume of the earth's crust. Because the plagioclases display a wide and generally consistent variation in composition, from soda-rich in the low-melting granites and rhyolites to lime-rich in the higher-melting gabbros and basalts, they have long been used by petrologists as one index of classification of the igneous rocks.

Many metamorphic rocks also contain plagioclase feldspars, and relations similar to those in the igneous rocks probably exist; in general, soda-rich plagioclases are found in rocks believed to have been metamorphosed at relatively low temperatures, and more lime-rich plagioclases in rocks believed to have been metamorphosed at higher temperatures. It is thus important that the methods used by petrologists to determine the compositions of plagioclases be as precise as is practicable; accordingly, intensive tests of optical and X-ray methods of plagioclase determination are now being carried out in this Laboratory.

In addition to the information afforded by the composition of a plagioclase, further clues to the genesis and thermal history of a rock may be found on close study of the plagioclase, because it is now known that the crystal structure of plagioclase of a given composition in a rock which cooled quickly from high temperatures is different from that of plagioclase of the same composition in a rock which either cooled slowly from high temperatures or formed at lower temperatures. These differences in the plagioclases have not yet been fully explored, and they have not been duplicated experimentally because of the extremely slow rates of the reactions accompanying falling temperature. Therefore, a study of variations in plagioclases from different rocks whose mode of origin can be interpreted from other geological evidence is being carried out.

Optical properties of plagioclase feldspars (J. R. Smith). The variation of optical properties with composition in plagioclases from thick stratiform mafic intrusions and from some pegmatites, granites, and metamorphic rocks has previously been investigated. The optical properties of fourteen chemically analyzed samples of plagioclase from other source rocks, mostly small hypabyssal bodies, have now been studied, with the object of investigating the variations to be expected in plagioclases from different sources. Variations in refractive indices are small, being such

that if the compositions of eleven of the samples were predicted from the measured refractive indices using the previously established curves, the predicted compositions would agree with the chemical analyses within ± 1.5 mol per cent anorthite. In the remaining three samples, the discrepancies in refractive indices are greater, and further work must be done before the reasons for the larger discrepancies will be known. In general, the optic axial angles and birefringences of the samples are subject to greater unpredictable variation than are the refractive indices, and are therefore less reliable indicators of plagioclase composition.

By heating natural plagioclases, it is possible to change them to the modifications which are stable at high temperatures, and the change in crystal structure can be readily confirmed by X-ray methods, as described below. In order to investigate the changes in optical properties accompanying the changes in crystal structure, chemically analyzed samples with known optical properties, covering the entire composition range with intervals of 10 mol per cent anorthite or less, are being heated at near-solidus temperatures, and remeasurement of the optical properties of the heated samples has been started.

Variations in X-ray powder patterns of plagioclases (J. R. Smith, Yoder). Following the discovery that the crystal structure of plagioclase feldspars is a function of thermal history as well as of composition, there has been a growing tendency to refer to "high-temperature" and "low-temperature" plagioclases, implying that two unique series of plagioclases exist. It is now known that plagioclases which are transitional between the two assumed series can be produced by heat treatment, but the assumption of two unique bounding series still remains. In reality, the term "high-temperature plagioclase" as used in the literature is not well defined, and there is very little evidence of a unique low-temperature series. The term "unique series" is used in the sense that in such a series any physical parameter is a single-valued function of composition (which function is not necessarily continuous).

In order to test the possibility that natural plagioclases fall into one or more unique series, peak separations in X-ray powder diffraction patterns of 65 chemically analyzed natural plagioclases were accurately measured, and plotted against the known compositions of the samples. Eleven plagioclases synthesized in the dry way and five synthesized hydrothermally were also studied. Some of the results of the study are shown in figures 9 and 10. Figure 9 shows the variation of the $2\Theta\ (1\bar{3}1) - 2\Theta\ (131)$ peak separation in dry synthetic plagioclases and in natural plagioclases from thick stratiform mafic intrusions. The points representing the dry synthetic plagioclases are closely fitted by the single-line curve drawn through them; the curve may be considered to represent plagioclases cooled very quickly from near-solidus temperatures. The points representing the natural plagioclases from thick stratiform mafic intrusions are closely fitted by a different single-line curve. These natural plagioclases have closely similar thermal histories, all of them having crystallized at basaltic magma temperatures, and, as a result of the tremendous thickness of the intrusions, cooled very slowly after crystallization. They appear to satisfy the concept of a unique series, but whether this is the "low-temperature" series is to be questioned. In figure 10, the points representing $2\Theta\ (1\bar{3}1) - 2\Theta\ (131)$ for all the other plagioclases studied are plotted against composition, with the curves of figure 9 as a basis for comparison. It will be noted that: (*a*) Most of the points representing sodic plagioclases from granites and pegmatites lie close to the dashed straight line, the slope of which differs markedly from that of the curve for plagioclases from thick stratiform mafic intrusions at a composition of about An_{35}. (*b*) Points representing oligoclases and andesines from volcanic rocks, certain other plagioclases designated in the legend

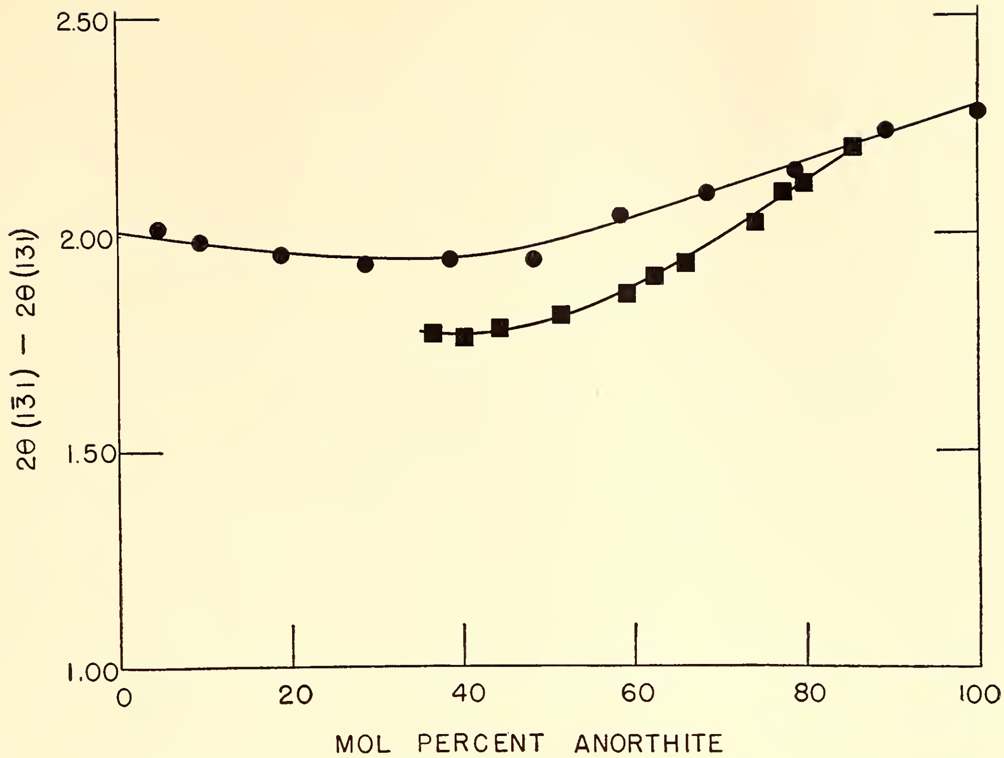

FIG. 9. Variation of 2Θ (1$\bar{3}$1) — 2Θ (131) with composition in dry synthetic plagioclases (circles) and in plagioclases from thick stratiform mafic intrusions (squares).

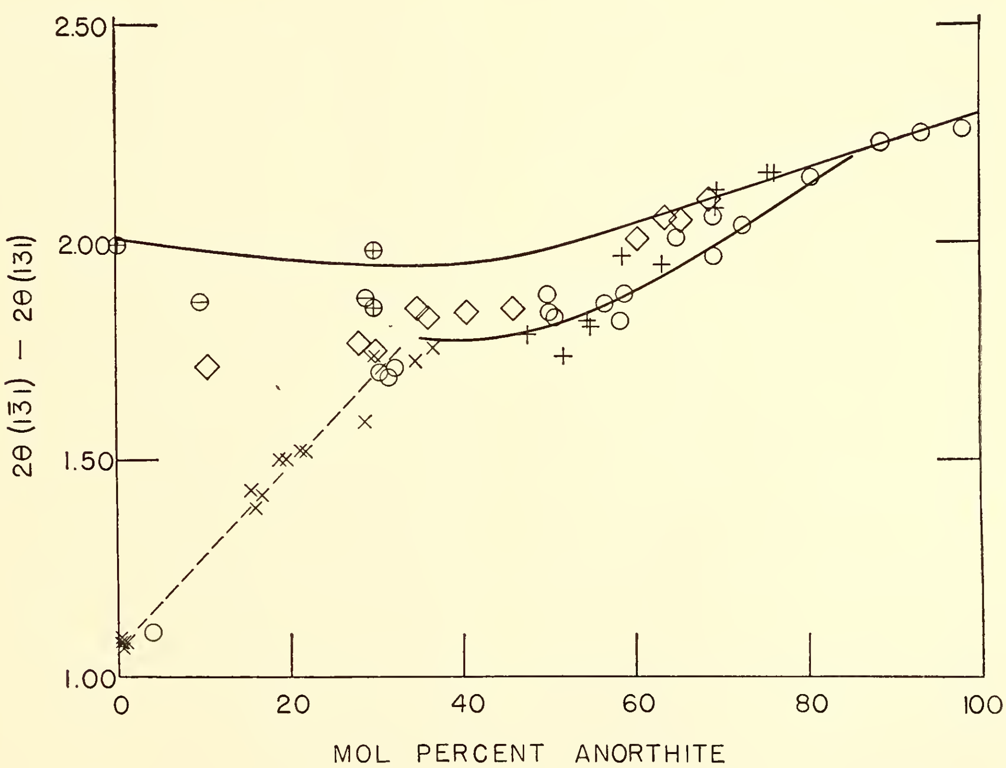

FIG. 10. Variation of 2Θ (1$\bar{3}$1) — 2Θ (131) with composition in plagioclases of various origins. The curves in continuous lines are the curves of figure 9. ×'s denote plagioclases from pegmatites and granites; diamonds, plagioclases from volcanic rocks; +'s, plagioclases from anorthositic rocks; open circles, plagioclases mostly from metamorphic and hypabyssal rocks; circles with horizontal bars, plagioclases synthesized hydrothermally; and circles with crosses, heated natural plagioclases.

for figure 10, and two plagioclases synthesized hydrothermally occupy intermediate positions, so that by this criterion these plagioclases are neither "high-temperature" nor "low-temperature" forms. (*c*) No two curves can represent all natural plagioclases in the composition range An_{30} to An_{80}.

It may be concluded that natural plagioclases do not all belong to two unique series. By studying groups of samples of plagioclases with similar thermal histories, it may ultimately be possible to define different series of natural plagioclases, each diagnostic of a different geologic environment or history.

Variations in single-crystal X-ray patterns of plagioclases (J. R. Smith, MacKenzie). It is now known that the atomic structures of natural plagioclases that have crystallized at relatively low temperatures or cooled very slowly from higher temperatures change discontinuously with composition. Briefly, pure albite is homogeneous and has a face-centered unit cell with a 7 Å *c* axis, albite-oligoclases of the peristerite type consist of two submicroscopic phases, andesines and labradorites display a super-lattice structure, bytownites have a body-centered unit cell with a 14 Å *c* axis, and anorthites have a primitive unit cell with a 14 Å *c* axis. On heat treatment, all these structures change toward the albite-type structure. The differences in structure, and the changes accompanying heat treatment, can be detected only in single-crystal X-ray photographs. In some cases, correlations between variations in the single-crystal patterns and in the optical properties and X-ray powder patterns are apparent, but a complete understanding of the correlations has not yet been achieved.

When the reasons for the complex and subtle variations found in the plagioclase feldspars are fully understood, and when rapid and convenient methods of detecting them have been established, a wealth of information bearing on rock genesis will be available to the petrographer.

Alkali Feldspars

The importance of the plagioclase feldspars in the classification of igneous rocks has been emphasized repeatedly. The role of the alkali feldspars, on the other hand, has always been secondary, chiefly because of their much more limited distribution. Even in alkaline or subalkaline rocks, the main consideration has generally been only whether or not an alkali feldspar is present. This fact is due mainly to a lack of knowledge of the complete phase relations of the alkali feldspars. Work in this Laboratory over a period of years has stimulated a new interest in the alkali feldspars and has resulted in the development of new methods for determining the nature of the feldspars characteristic of different rock types. Work in this field has been continued on two specific projects.

The alkali feldspar solvus (MacKenzie, J. V. Smith). In their study of the system $KAlSi_3O_8$—$NaAlSi_3O_8$—H_2O, Bowen and Tuttle determined experimentally a solvus for the alkali feldspars. This solvus they found to be virtually independent of pressure, and it would therefore appear to make an ideal geologic thermometer. The solvus determined for synthetic feldspars is, however, applicable to natural feldspars only if they are high-temperature forms and have a calcium content low enough so that the effect of calcium in raising the temperature of the solvus may be ignored. Even if these conditions are satisfied, the practical difficulty of determining the composition of the intimately intergrown phases in an unmixed specimen must be overcome. It should be noted, however, that, since this unmixing is a fairly rapid process, a rock containing one feldspar of composition about $Or_{50}Ab_{50}$ which shows no sign of having unmixed was undoubtedly quenched at a temperature above 660° C, the maximum temperature of the solvus in the system $NaAlSi_3O_8$—$KAlSi_3O_8$.

The X-ray powder diffraction method of

determining the composition of the separate phases in a cryptoperthite is known to give impossible results in some cases, probably as a consequence of strain in the lattices of the two phases. In an attempt to find an alternative method for determining the composition of the separate phases, single-crystal X-ray techniques were used. The reciprocal lattice angles of the sodium feldspar phase were determined by the method described last year (Year Book No. 53). The composition of the sodium-rich phases as determined by the single-crystal method differed from those obtained by the powder method by as much as 15 per cent Or. We have thus far been unable to resolve this difficulty or to decide which of the methods gives a closer approximation to the true composition of the sodium-rich phase, but in no case have impossible results been obtained for the composition of the sodium phase by single-crystal methods.

Alkali feldspars in granites (MacKenzie, J. V. Smith). It has so far proved impossible to synthesize feldspars corresponding to the natural low-temperature minerals found in some granites and pegmatites, so the complete phase relations of the alkali feldspars have not been experimentally determined. Field studies supplemented by more detailed laboratory work might, however, eventually make it possible to deduce these relations. A systematic mineralogical study of specimens from three of the four series of alkali feldspars has been prepared for publication and has given us a more complete picture of the sequence of changes which occurs in the feldspars under conditions of very slow cooling in plutonic rocks or in pegmatites.

A study of the feldspars in granites of the British Tertiary province has been undertaken with the object of relating the detailed changes in the feldspars with their geologic environment. The optic angles of crystals removed from selected specimens are measured and a single-crystal X-ray photograph is taken of each crystal. The complete sequence of changes from a sanidine-cryptoperthite to an orthoclase-microperthite to a microcline-perthite has not yet been found in one rock mass, but it is believed that such a series will be found and will give very valuable information on the physical conditions at the time of emplacement of the rocks.

The system $NaAlSiO_4$—$NaAlSi_3O_8$—H_2O (MacKenzie). The investigation of this system is a preliminary to the study of the silica-poor part of the system $NaAlSiO_4$ — $KAlSiO_4$ — SiO_2 — H_2O, the importance of which was discussed briefly last year (Year Book No. 53).

The equilibrium relations have been studied at water vapor pressures of 1000 and 2000 bars, and the investigation is now being extended to 3000 bars. The minimum melting temperatures at 1000 and 2000 bars are 780°[1] ± 7° C and 720° ± 7° C, as compared with 1068° ± 5° C in the system $NaAlSiO_4$—$NaAlSi_3O_8$.

The similarity of some of the properties of nepheline to those of albite has led to a more detailed study of these two phases. X-ray investigations of nepheline and albite have shown that both minerals have rapid, displacive inversions, and in each case the temperature of the inversion is inversely related to the temperature of crystallization. In the case of albite it was considered that there were two distinct high-temperature modifications, one of which became monoclinic at elevated temperature, the other remaining triclinic up to its melting temperature. The temperature of the change from one high-temperature form to the other is not accurately known, and experiments have been performed to obtain more details of the nature of this inversion. A glass of albite composition, crystallized in the presence of water vapor at various temperatures over the range 500° to 1000° C, produces crystals in which there is a gradual change in X-ray spacings with temperature of crystal-

[1] Misprinted as 870° in Year Book No. 53.

lization. Tuttle and J. V. Smith found slight differences between the lattice parameters of nepheline crystallized at 1150° C and those of nepheline crystallized at 850° C in the presence of water vapor.

It is probable that slight differences will be detected in the lattice parameters of many silicates prepared in the laboratory, and until the magnitudes of these differences are investigated, descriptions of unique physical properties should be accompanied by details of the methods of synthesis.

Micas

During the past year our understanding of the occurrence and field relations of paragonite has increased, and the join muscovite—paragonite has been worked out in the laboratory. By combining the results on the micas with our understanding of the alkali feldspars, we can now interpret one of the commonest mineral assemblages in nature, the mica—feldspar assemblage.

Paragonite (Eugster, Yoder). Inquiry into the occurrence of paragonite in nature has revealed that in some areas this mineral is one of the major rock-forming silicates. Its occurrence is shown to be less restricted than was previously assumed. The chief control seems to stem from the bulk composition of the rock.

During the past year the importance of paragonite in several metamorphic areas in New England was demonstrated. It was thought desirable to extend these studies to a comparable group of rocks in an entirely different metamorphic region. An excellent opportunity to do this came during a recent trip to the central part of the Alps. In addition to the type locality of paragonite (Alpe Sponda, Ticino, Switzerland), eight metamorphic provinces were visited. X-ray investigations revealed that in five of these areas paragonite is a common and abundant mineral.

Paragonite was found to be present in specimens from the following geological regions in Switzerland: Val Russein, Aarmassiv; Frodalera–Bronico–Pian Segno, Lukmanier Pass; Alpe Crozlina–Pizzo Campo Tencia, Ticino; Lago Leid–Campolungo Pass, Ticino; Landarenca, Ticino. The environment in which paragonite was found varies from that of fine-grained sediments, phyllites, muscovite-biotite-gneisses, staurolite-albite-schists, muscovite-garnet-schists, and kyanite-staurolite-schists to that of paragonite-kyanite lenses within quartz veins.

Three provinces in which paragonite was also expected to occur, on the basis of the bulk composition of the rocks, did not show its presence. They are: Pizzo Scopi, Lukmanier Pass; Val Piora–Ritom See, Ticino; Tremola Series, St. Gotthard. The absence of paragonite in these areas must be substantiated by more thorough sampling.

This preliminary study has borne out our theory, based on experimental studies, that paragonite can form under a wide range of conditions.

The join muscovite—paragonite (Eugster, Yoder). During the investigations on natural micas it became evident that the unit cell dimensions of coexisting muscovites and paragonites vary considerably. The largest variation was observed in the *c* spacing, which can be shown to be primarily dependent on the *Na/K* ratio of the micas. It was concluded from mineral assemblages that the amount of solid solution between the two micas is largely dependent on the temperature of formation. In order to determine the limits of solid solution, runs were made on the join muscovite—paragonite. The preliminary results are presented in an equilibrium diagram (fig. 11). The amount of paragonite in solid solution in muscovite at a given temperature was obtained by measuring the position of the (006) reflection and assuming a straight-line relation between the *c* spacings of the two end members. Unfortunately, paragonite did not crystallize well enough on the join muscovite—paragonite to make accurate measurements

of its cell dimensions possible. The solvus on the paragonite side was therefore determined by using natural muscovite—paragonite assemblages and fixing their temperature of formation with the aid of the solvus for synthetic muscovites. Considerable inaccuracy is introduced because of the effects of fluorine, calcium, iron, and other ions on the *c* spacing of the micas. The solvus determined in part from synthetic materials can, however, be applied if the Na_2O content of the natural muscovite and the K_2O content of the natural paragonite are determined chemically. It is assumed that the influence of such ions as fluorine, calcium, and iron on the slope of the solvus will be small.

Below the breakdown of paragonite the system is pseudobinary; all phases present can be expressed in terms of the end members, with the exception of the vapor. Above the stability fields of muscovite and paragonite, the system becomes quaternary. The experimental data indicate that the maximum amount of solid solution of paragonite in muscovite (24 mol per cent at 30,000 pounds per square inch) is reached above the breakdown temperature for pure paragonite (660° C at 30,000 psi). From the position of the determined points it can also be deduced that a soda-bearing muscovite breaks down at a slightly lower temperature than a pure muscovite. Although the tie lines muscovite solid solution to feldspar solid solution do not lie in the binary system, the Na/K ratio of the

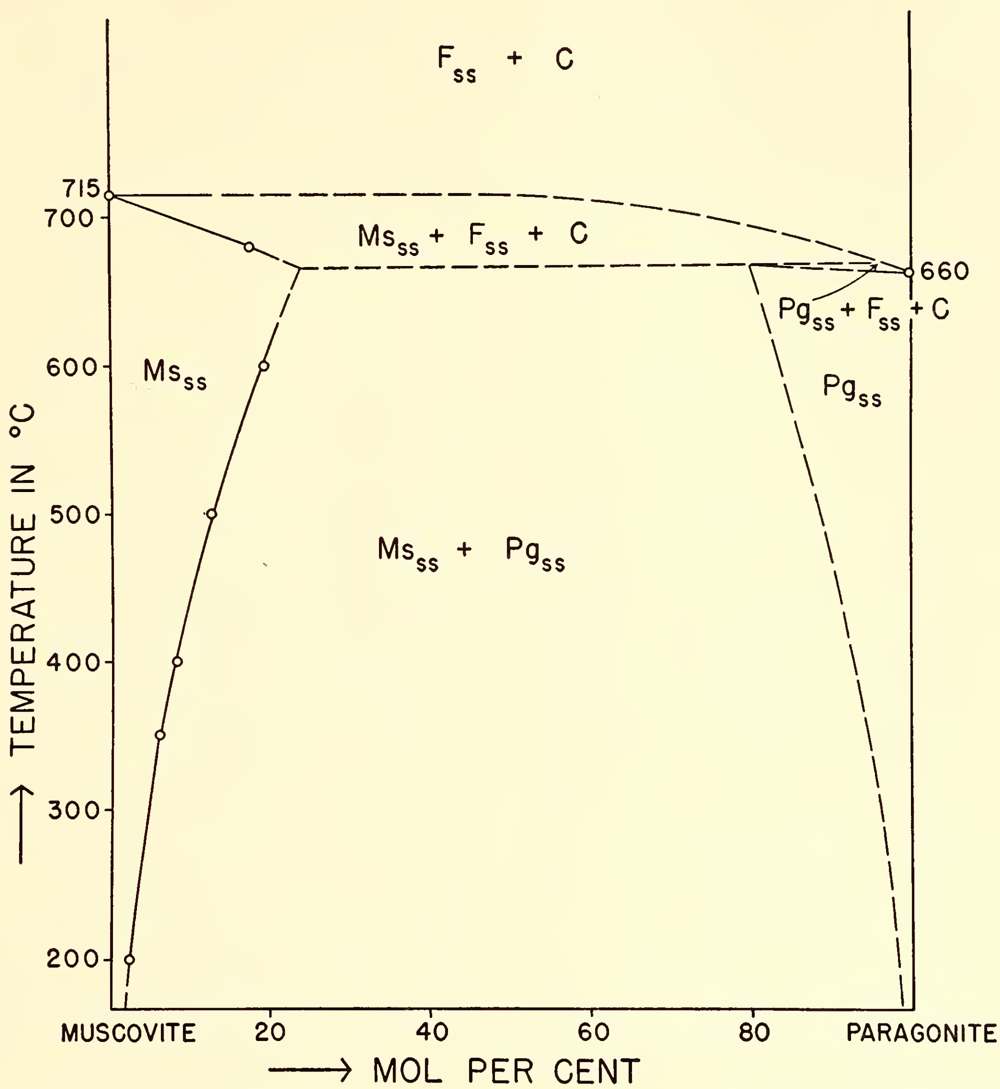

FIG. 11. Preliminary phase diagram for the subsolidus region of the muscovite—paragonite join

feldspar in equilibrium with a muscovite can still be represented correctly.

In constructing the diagram it has been assumed that addition of K_2O to paragonite raises the stability limit of paragonite slightly. Support for this assumption can be found in the results of the experiments on the join muscovite—albite (see below). On this basis, the paragonite in the three-phase region paragonite—feldspar—corundum has a larger K/Na ratio than the albite in equilibrium with it. The points fixed experimentally at 30,000 psi greatly restrict the temperature range within which the breakdown of paragonite richest in potash may occur. It can be expected that this temperature will be less than 10° higher than that for pure paragonite, and it therefore lies within the experimental error for pure paragonite.

The position of the muscovite—paragonite solvus will probably not be affected greatly by changes in the total or partial water pressure. The temperature at which the solvus is truncated, however, is closely approximated by the P-T curve for the reaction paragonite $\rightleftharpoons$ albite + corundum + vapor (see Year Book No. 53), and it is therefore pressure-dependent. This difference in pressure dependence can be used to estimate the minimum partial water pressure at which muscovite—paragonite assemblages have formed.

Measurement of the *c* spacings on all available muscovite—paragonite assemblages showed that the approximate temperatures determined from the amount of solid solution do not conflict with deductions from mineral assemblages and geological environment. The smallest differences between c_{ms} and c_{pg} were found in the kyanite-staurolite schists from Alpe Sponda. The largest difference between the basal spacings, i.e. the smallest extent of solid solution, was found in some of the very fine-grained micaceous phyllites.

In the laboratory, equilibrium cannot be attained by using mixtures of pure natural micas. Reaction rates are much faster, however, when synthetic preparations are used as initial charges. Mixtures of nearly pure natural muscovite and paragonite were held for one to two months at different temperatures. The muscovite showed an increase of the Na_2O content which was accentuated at higher temperatures. The paragonite showed no change. In the synthetic mixtures the muscovite that grows first is almost soda-free, and very slowly some Na_2O is taken up into it.

The system potassium feldspar—albite—corundum—water (Eugster, Yoder). Feldspars are commonly associated with white micas, and it is therefore of interest to consider the feldspar-mica equilibria. Disregarding water as the fourth phase, all phases can satisfactorily be represented in the ternary diagram potassium feldspar—albite—corundum. A sequence of isothermal sections based on the experimental data is presented in figure 12. The triangles are drawn in mol per cent.

Below 650° C the feldspars unmix, according to Bowen and Tuttle. There will be regions in which three of the four phases—two feldspars and two micas—are in equilibrium with one another. It was necessary to determine in the laboratory which of the two possible joins, albite$_{ss}$—muscovite$_{ss}$ and potassium feldspar$_{ss}$—paragonite$_{ss}$, is the more stable at a given temperature. It could be shown by using mixtures of natural potassium feldspar and paragonite that the reaction potassium feldspar$_{ss}$ + paragonite$_{ss}$ $\rightleftharpoons$ albite$_{ss}$ + muscovite$_{ss}$ over the entire temperature range investigated (between 300° and 600° C) is displaced toward the right-hand side. This conclusion is supported by the mineral assemblages found in nature. It is an illustration of the fact that in feldspar—mica assemblages sodium preferentially enters the feldspar lattice, whereas more potassium will be present in the mica lattice.

The composition of the feldspars in equilibrium with muscovite at 600° and 500° C has been taken from the feldspar solvus as determined by Bowen and Tuttle.

More work in the two feldspar–two mica regions will have to be done before

all reactions can be predicted quantitatively. The data presented point out the direction of further attack.

plex natural minerals can most easily be reached through their pure synthetic end members. Since the ordered and dis-

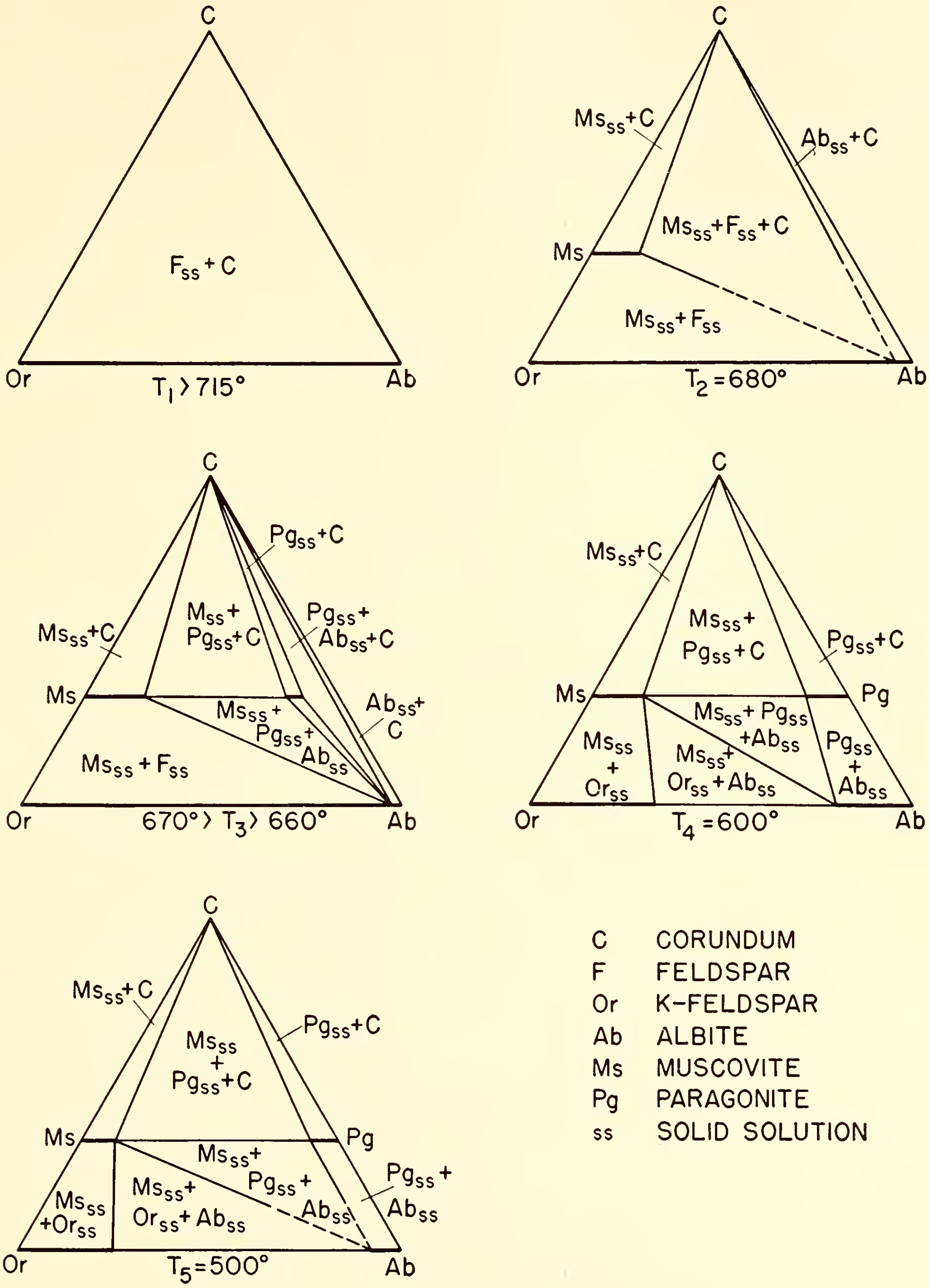

FIG. 12. Mineral assemblages in the system albite—potassium feldspar—corundum—water at selected temperatures and 30,000 psi water pressure. The hydrous phases are projected onto the albite—potassium feldspar—corundum plane.

Muscovite (Yoder, Eugster). The three-year study of the muscovites has now been prepared for publication. The many interesting results have again demonstrated the usefulness of an underlying premise of the Laboratory: an understanding of the complex natural minerals can most easily be reached through their pure synthetic end members. Since the ordered and dis-

ordered, one-layer, monoclinic muscovite structures were first recognized in synthetic micas, they have been found to be very common among the natural varieties of muscovite; for example, sericite, pinite, illite, gieseckite, groppite, hydromica, sec-

ondary mica, mariposite, sarospatakite, potash bentonite, and glimmerartiger Ton. Although most of these minerals are varieties of muscovite, the common illites, hydromicas, and sericites were examined in greater detail. The three representative substitution schemes deduced from these dioctahedral minerals are, respectively: (*a*) Si→KAl, (*b*) H_3O→K, (*c*) MgSi→2Al. A fourth, but limited, possibility is 2Mg→KAl, which involves solid solution with the trioctahedral micas. All four substitution schemes could take place in a dioctahedral mica. Mixed-layer structures have added considerable confusion to the general problem of substitution.

On the assumption that the substitution schemes (*a*), (*b*), and (*c*) are the major replacement mechanisms in the dioctahedral micas, it is possible to plot the composition of such complex materials in the system muscovite — Al-celadonite — pyrophyllite and their iron analogues (fig. 13). A point in such a system may be specified uniquely by considering only (1) the tetrahedrally co-ordinated atoms required to satisfy the silicon position and (2) the sum of the octahedrally co-ordinated ions having a valence of 3. The advantage of these two features is that they do not involve the properties that are hard to determine, such as the alkalies, H_3O^+, exchangeable ions, and the $M^{+2}O$ group, which as a group represents the third co-ordinate in figure 13. It is concluded from this plot that the minerals are well represented in

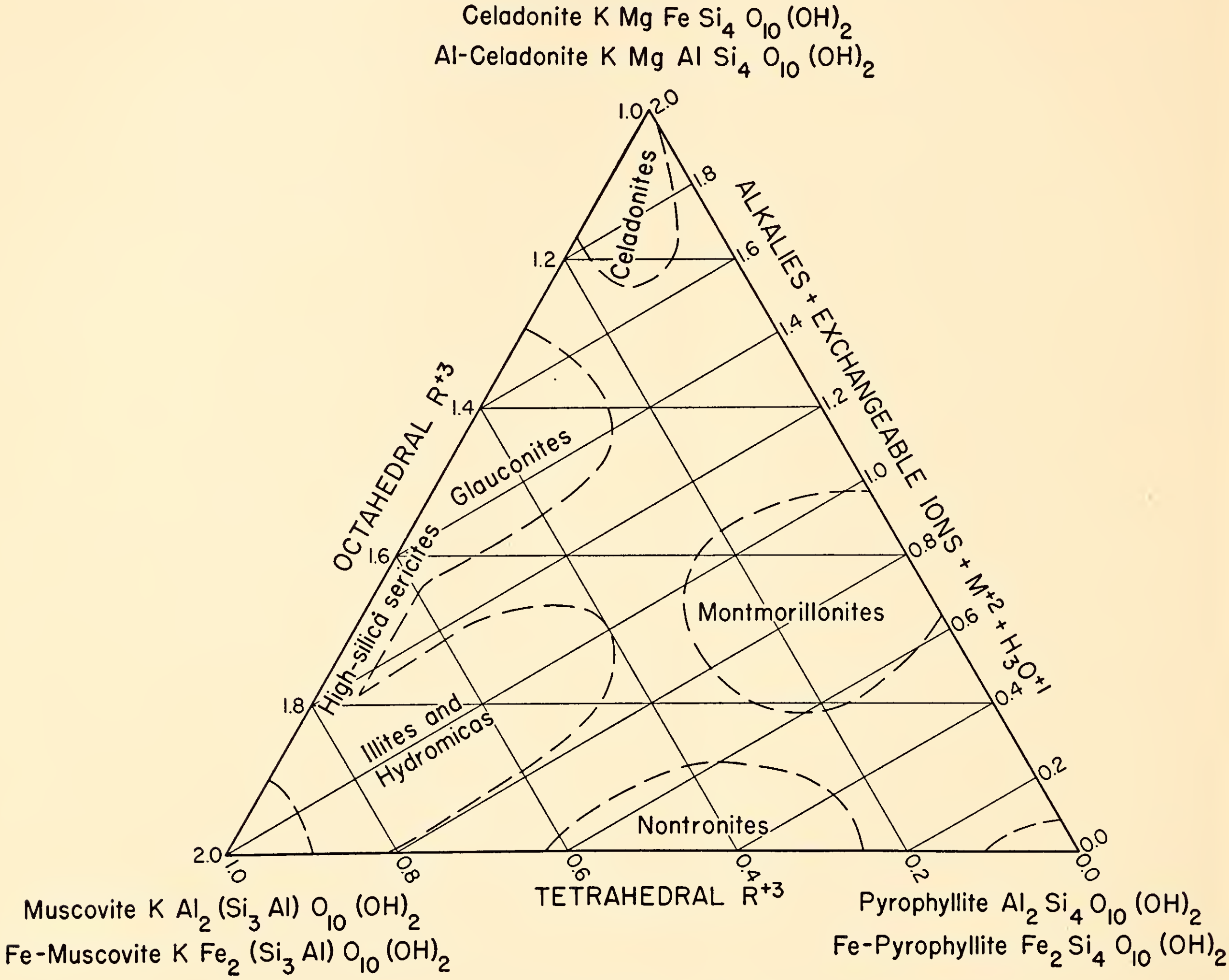

FIG. 13. Plot of tetrahedral R^{+3} and octahedral R^{+3} in atom proportions of dioctahedral micas and related minerals. The wide extent of the fields is due in part to the presence of mixtures or mixed-layer assemblages, and not wholly to solid solution.

the chosen system by the proposed substitution schemes. There is no doubt but that the wide extent of the field of each mineral group is due partly to mixtures or mixed-layer assemblages, and not wholly to solid solution. Synthesis studies in this system may aid considerably in defining the limits of the proposed substitutions.

Sulfides, Selenides, and Tellurides

The system Cu—Fe—S (Greig, Jensen, Merwin). Because of the importance of the sulfides of iron and copper in ores, physical-chemical study of them was started at the Geophysical Laboratory shortly after the Laboratory was established. The results of the first extensive study appeared in 1912 ("The Mineral Sulfides of Iron," Allen, Crenshaw, Johnson, and Larsen). The results of a similar study of the sulfides of copper appeared in 1915 ("The Sulfides of Copper," Posnjak, Allen, and Merwin). In these investigations, in order to heat the sulfides under the equivalent of different pressures of sulfur vapor, heatings were made in "vacuum," under 1 atm of hydrogen sulfide, and under 1 atm of sulfur vapor.

Subsequently, Allen and Lombard developed a method by which a charge of sulfide could be maintained at a constant temperature under a selected constant pressure of sulfur vapor. This was done by using a glass tube having a small bulb at each end; one bulb contained the sulfide charge, and the other contained pure sulfur. After the tubes were evacuated and sealed, the bulbs were heated separately. The temperature of the sulfur was kept below that of any other part of the system to prevent condensation. Hence, the sulfur pressure on the sulfide was controlled by the temperature of the sulfur in the bulb.

Using this technique, Merwin and Lombard studied equilibrium in that part of the system Cu—Fe—S within which the compositions of the naturally occurring sulfides of iron and copper lie. The results of this investigation were published in 1939. This paper presented an equilibrium diagram for the system Cu—Fe—S under a sulfur pressure of 455 mm. The temperature range covered by the diagram was from 411° C, at which liquid sulfur has a vapor pressure of 455 mm, to the temperature at which the sulfides begin to melt under this pressure of sulfur vapor. In addition, the paper contained many data on equilibrium at other sulfur pressures, and the results of a large number of experiments in which charges were melted under their own vapor pressure, cooled rapidly, and examined under the microscope to learn the phases that had crystallized in them.

At this point, although the sulfide work had included the determination of the melting temperatures of a number of iron sulfides and copper sulfides, no systematic study of phase relations at melting temperatures had been carried out. After the publication of Merwin and Lombard's paper, some experiments (not published) were made, testing the suitability of a number of methods for finding the temperatures of the beginning and completion of melting of some of these sulfide solid solutions. From these tests it appeared that the most hopeful method was a combination of thermal analysis and quenching experiments. Thermal analysis could be carried out by making heating and cooling curves on charges of sulfide contained in evacuated bulbs of silica glass with such a small vapor space over the sulfide that the total sulfur present in it—which would, of course, come from the sulfide charge—would change the composition of the sulfide but slightly. In this way the composition of a material under thermal analysis could be controlled closely. In quenching experiments a charge is held at a constant temperature for a few minutes, some hours, or even days, then chilled as rapidly as possible to minimize reorganization of the material during cooling. Samples of the quenched charge are then examined under the microscope to learn what phase

or phases were present in it at the temperature of the run. The charges for such experiments can also be contained in small evacuated bulbs of silica glass. Although it has been quite impossible to prevent crystallization of these sulfide liquids during cooling, quenchings were found to be valuable in several ways. It is possible by quenching experiments to fix within limits the lowest temperature at which melting occurs at equilibrium, and thus to place a lower limit on the temperature range within which heat effects shown by heating and cooling curves can be caused by melting. In general, quenchings on these materials will not fix the temperature of the liquidus—the temperature at which a liquid of the composition of the charge can coexist in equilibrium with a crystalline phase, spoken of as the primary phase. In some narrow composition ranges in this system, however, it is possible by quenchings to determine the primary phase and to fix the temperature of the liquidus within limits. In some, but not in all, cases in which more than one phase crystallizes, the spatial relations of the phases present in quenched charges can give information that is helpful in interpreting heating and cooling curves. In these materials, however, the type of information that may be obtained by quenching differs from composition to composition in the system, and, in general, the results are not so unequivocal as those obtained by quenching experiments on silicates. Because of the rapidity with which reorganization occurs in charges of these materials at temperatures just under those of melting, long runs at constant temperature followed by quenching and microscopic examination will serve to outline the composition ranges of solid solutions.

In February 1940 Dr. Einar Jensen came to the Geophysical Laboratory as a guest investigator on a scholarship from the University of Oslo, and employing the methods just mentioned—thermal analysis supplemented by quenchings—began work on the melting relations of pyrrhotite; that is, he began to work out the equilibrium relations between liquid and crystals in a part of the system Fe—S. The invasion of Norway in the spring of 1940 soon cut off his source of funds, and he was subsequently appointed a Research Associate of the Carnegie Institution of Washington. After working out the melting relations of pyrrhotite over the range of compositions to which the equipment with which he began his work was applicable without modification, he made a like investigation of the melting relations of the copper sulfide chalcocite, and then extended the investigation to ternary compositions lying between the compositions that he had studied in the binary systems Fe—S and Cu—S and to other ternary compositions of lower sulfur content. In these ternary mixtures, in addition to the changes of rates of heating and of cooling occasioned by phase changes in the melting interval, he found and recorded others occurring below the melting interval.

In the meantime the Geophysical Laboratory had undertaken a program of investigations relating to ordnance for the National Defense Research Committee, and when this program got under way Dr. Jensen stopped working on the sulfides in order to devote his full time to this program. After the war was over he returned to Norway, so that the work he had been doing on the sulfides remained uncompleted.

While the work was in progress Dr. Jensen prepared a paper on the first part of it, "Pyrrhotite, Melting Relations and Composition," which was published in 1942. After he returned to Norway he prepared and published a paper on the corresponding work in the system Cu—S, "Melting Relations of Chalcocite" (1947). Both papers presented equilibrium diagrams.

There remained the more extensive work on the ternary mixtures. He analyzed his heating and cooling curves; tabulated the temperature of the liquidus, of the first indication of melting, of intermediate "breaks," and of solid phase trans-

formations; prepared diagrams showing these data graphically; and prepared a detailed description of the work and a discussion of the results. From these data alone, however, it proved impractical to work out the equilibrium relations in all parts of the composition range covered by the experimental work, and hence to draw up a satisfactory equilibrium diagram showing them. The chief questions needing answers related to the relation of chalcopyrite solid solution to the rest of the system. Some of the questions might have been answered by heating and cooling curves made on additional preparations whose compositions were chosen for the purpose. It appears likely, however, that satisfactory answers to the more important questions could have been obtained only by an additional systematic study by means of quenching experiments and microscopic examinations designed to answer them, and this had not yet been carried out when the work was stopped. He has had no opportunity since for additional experimental work.

A large number of samples of preparations from earlier work in this composition range were at the Geophysical Laboratory in Merwin's care. The possibility remained that by a microscopic study of them enough information about phase occurrence and relations might be obtained to complement the data that Jensen had obtained, to answer some of these questions, and to permit drawing up an equilibrium diagram. This has proved to be the case. These preparations have been examined in detail by Merwin and Greig, and the information so obtained, combined with the thermal analytical data and with published data obtained by workers at other laboratories, has made it possible to draw up the equilibrium diagram presented in figure 14. A paper presenting this diagram and the data on which it is based, and discussing them in detail, is in the course of preparation by Greig.

This equilibrium diagram may be thought of as showing, for the composition range covered, the equilibrium relations between liquid and crystals as they would be under a constant piston pressure just sufficient to condense the sulfur vapor in those materials having the highest vapor pressure. As this pressure is but a very few atmospheres, the equilibrium temperatures under it probably depart from the corresponding temperatures under the actual conditions of the experimental determinations (pressure that of the sulfur vapor) by less than the errors in the determinations. This "removal" of the vapor phase by considering it to be condensed greatly simplifies the expression of the equilibrium. The diagram represents equilibrium between liquid and crystals, but does not represent equilibrium at temperatures above or below those at which liquid and crystals coexist.

If the reader will imagine a solid model representing composition in the plane of the paper and temperature in the direction at right angles to it increasing upward, and will visualize two composite surfaces in the model, the relations shown by the diagram will become evident. The upper of these composite surfaces represents the liquids that can coexist in equilibrium with crystals, and is spoken of as the liquidus or the liquidus surface. The lower represents the crystals that can coexist in equilibrium with these liquids, and is spoken of as the solidus or the solidus surface. The diagram shows the projection of the liquidus surface and of parts of the solidus surface on the composition plane (the plane of the paper). To save space, that part of the full equilibrium diagram that represents compositions low in sulfur has been left out.

The shape of the liquidus surface is shown by the isotherms, exactly as the contours on a topographic map show the shape of the surface of the land. It will be seen that this surface is composite, being made up of several curved surfaces or fields that intersect one another along curves—spoken of as liquidus field boundaries—and that each of these fields is

labeled. In these and other labels the term or terms before the bracket denote the phase or phases represented by points in the field bearing the label; the term or terms within the bracket denote the phase or phases with which it or they can coexist in equilibrium.

It will be seen that in the labels on some liquidus fields there is a single term in front of the bracket and that in the labels on others there are two. Thus two types of liquidus field are shown. The field labeled *Liq. B,* (*Chalcocite S.S.*) is an example of the first type, that labeled *Liq. A+Liq. B,* (*Chalcocite S.S.*) an example of the second. Any point on a liquidus field of the first type represents, in temperature and composition, a single liquid that can coexist in equilibrium with one crystalline phase. Any point on a liquidus field of the second type represents a mixture of a conjugate pair of immiscible liquids that can coexist in equilibrium with a single crystalline phase. To each field of the first type on the liquidus surface there corresponds a conjugate field on the solidus surface, any point on which represents the crystalline phase that can coexist in equilibrium with the liquid represented by a point on the liquidus field. Lines joining these conjugate points are tie lines. Projections of such fields are shown as shaded areas on the equilibrium diagram. Thus the shaded field on the solidus labeled CHALCOCITE S.S., (LIQ. B), which may be spoken of as the *B* solidus field of chalcocite solid solution, is conjugate to the liquidus field labeled *Liq. B,* (*Chalcocite S.S.*), which may be spoken of as the *B* liquidus field of chalcocite solid solution. No tie lines are shown on the equilibrium diagram, but, if the diagram were complete, enough tie lines would be shown so that the tie line connecting any point on a liquidus field of this type to the conjugate point on the conjugate solidus field could be drawn. Or, alternatively, the same information would be shown by a combination of isotherms on the solidus fields of each solid solution, and isotherms and fractionation curves[2] on their liquidus fields.

Any point on the curve along which the *B* liquidus fields of two solid solutions intersect is conjugate to two points on the solidus surface. One of these points lies on a boundary curve of the *B* solidus field of one of the solid solutions, the other on the corresponding boundary curve of the *B* solidus field of the other solid solution. Thus the three phases represented by these three points can coexist in equilibrium. The triangle joining them is spoken of as a three-phase triangle. As an example consider any point on the curve along which the *B* liquidus fields of chalcocite solid solution and pyrrhotite solid solution intersect. The point represents, in temperature and composition, a liquid that can coexist in equilibrium with pyrrhotite crystals of the composition represented by the conjugate point on that boundary curve of the *B* solidus field of pyrrhotite that joins the points at 950° and 912° C, and with crystals of chalcocite solid solution represented by the conjugate point on that boundary of the *B* solidus field of chalcocite solid solution that joins the points at 950° and 912° C.

The point at which the *B* liquidus fields of three solid solutions intersect is conjugate to three points on the solidus surface, each such point lying at a corner on the boundary of the *B* solidus field of one of the three solid solutions. Thus these four points represent four phases that can coexist at equilibrium. For example, the point at which the *B* liquidus fields of chalcocite, pyrrhotite, and chalcopyrite solid solutions intersect represents a liquid at 950° C that can coexist with crystals of chalcocite solid solution, with crystals of chalcopyrite solid solution, and with crystals of pyrrhotite solid solution represented by the points at 950° C on the boundaries of the *B* solidus fields of chalcocite solid

[2] A curve on the liquidus surface so drawn that at each point on it the tie line from that point is tangent to it.

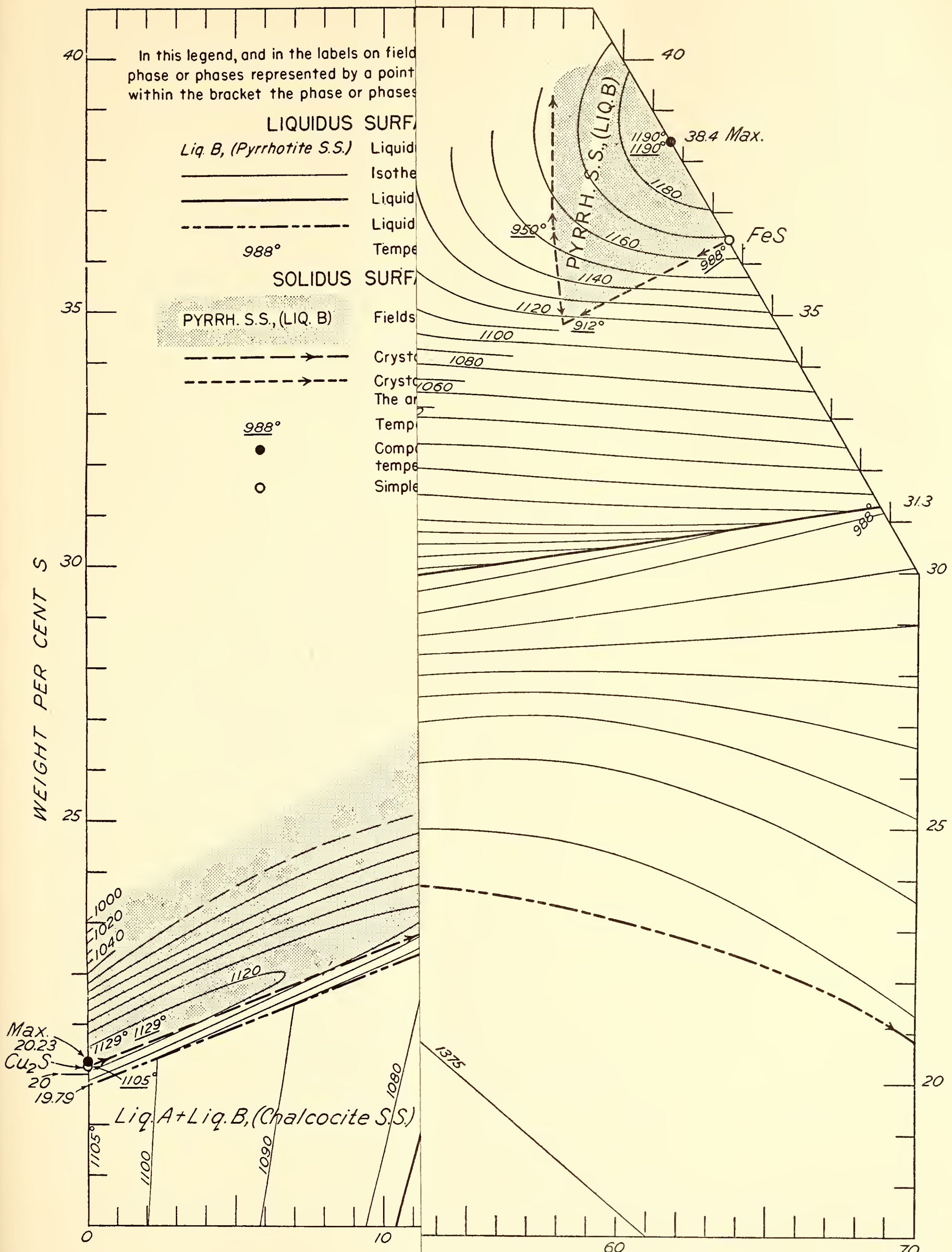

FIG. 14 … e liquidus surface.
Schüller.

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[2] A curve on the liquidus surface so drawn that at each point on it the tie line from that point is tangent to it.

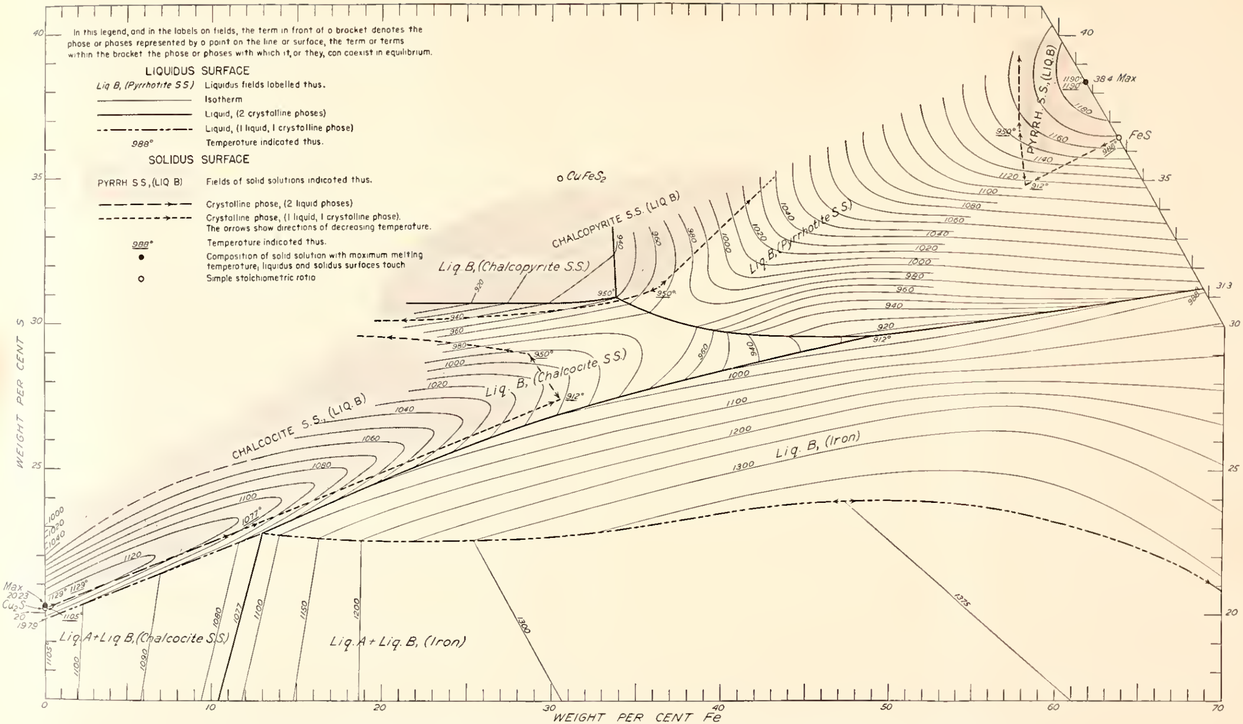

FIG. 14. Diagram showing equilibrium relations between crystals and liquid for a part of the system Cu—Fe—S. The isotherms are drawn on the liquidus surface. The shaded areas are solidus fields, each of which is conjugate to a liquidus field. The lower part of the diagram is from Schlegel and Schüller.

solution, chalcopyrite solid solution, and pyrrhotite solid solution, respectively.

What has been said about *B* liquidus and *B* solidus fields applies also to *A* liquidus and *A* solidus fields. No such fields appear, however, on that part of the complete equilibrium diagram that is included in this diagram.

Now consider the liquidus fields representing conjugate pairs of immiscible liquids that can coexist in equilibrium with a crystalline phase. Each member of such a pair of conjugate liquids is represented in temperature and composition by a point on the curve bounding the field. The tie line joining them is an isotherm crossing the field. Both liquids of such a pair are also conjugate to the crystalline phase with which they can coexist in equilibrium. This crystalline phase is represented by a point on the curve of intersection of the *A* solidus field and the *B* solidus fields of the phase. For example, the liquid *B* of one such conjugate pair of liquids is represented by the point at which the 1090° C isotherm meets the boundary of the field labeled *Liq. A* + *Liq. B,* (*Chalcocite S.S.*). The point representing the other conjugate liquid lies at the point at which the isotherm crosses the opposite boundary of this field. This point lies at less than 1 per cent sulfur, however, and thus is outside this diagram. The chalcocite solid solution with which these two liquids can coexist in equilibrium is represented by the point at 1090° C on the curve that bounds the *B* solidus field of chalcocite solid solution on the low-sulfur side and extends from the Cu—S side line to the point at 1077° C. This curve is shown on the diagram as a long-dashed line. It is the curve of intersection of the *B* solidus field of chalcocite solid solution with its *A* solidus field. The latter field extends downward from this curve in the solid model, but, as the field is nearly vertical, its projection does not show on the diagram. The conjugate *A* liquidus field of chalcocite solid solution extends downward from the boundary of the field *Liq. A* + *Liq. B,* (*Chalcocite S.S.*) on the low-sulfur side, but its projection is outside the area included in this diagram.

The fields labeled *Liq. A* + *Liq. B,* (*Chalcocite S.S.*) and *Liq. A* + *Liq. B,* (*Iron*) intersect along the line at 1077° C, which is a field boundary, an isotherm, and a tie line joining points representing conjugate liquids *A* and *B*. Points on this line represent a mixture of a pair of conjugate liquids that can coexist with two crystalline phases. One of these crystalline phases is the chalcocite solid solution represented by the point at 1077° C on the boundary of the *B* solidus field of chalcocite. The other is metallic iron, represented by a point that lies outside the area included in this diagram.

The only solidus fields shown on the diagram are those that represent a single solid solution that can coexist in equilibrium with liquid. This does not, however, result in the diagram's containing less information than it would if all the solidus fields were shown, for any crystalline phase that occurs in equilibrium with liquid is represented by a point on the *A* or *B* solidus field of that phase, or on its boundary, and the other solidus fields are completely determined when all such fields and their boundaries have been determined.

The reliability of the various parts of the equilibrium diagram can best be judged by the data on which they are based, and therefore cannot be discussed without the data. It may be said, however, that the general relations are believed to be essentially as shown. Most of the liquidus surface is believed to be reliable. The actual composition of the ternary eutectic that is represented by the point at which the *B* liquidus fields of chalcocite solid solution, of pyrrhotite solid solution, and of iron meet is in some doubt, as is the position of the lower part of the curve along which the *B* liquidus fields of iron and of chalcocite solid solution intersect. The positions of the boundaries of the solidus fields, in general, are not well established, but the general relations of these fields to the

liquidus fields and to each other are believed to be as shown.

The fields labeled *Liq. A + Liq. B,* (*Chalcocite S.S.*) and *Liq. A + Liq. B,* (*Iron*), as well as the slope of the upper part of the field labeled *Liq. B,* (*Iron*), have been taken from data published by H. Schlegel and A. Schüller (*Die Schmelz- und Kristallisationsgleichgewichte im System Cu—Fe—S und ihre Bedeutung für die Kupfergewinnung,* 1952).

The system Fe—Ni—S (Kullerud). Systematic studies of the subsolidus reactions taking place in this system aid in determining the pressure and temperature conditions that existed during the formation of various iron-nickel-sulfide ores and give us an understanding of the processes which were responsible for this kind of ore deposition.

The most important problem in this system is the pyrrhotite ($Fe_{1-x}S$)—pentlandite ($(Fe,Ni)_9S_8$) relationship. Pentlandite is the most important nickel ore mineral. Since the pyrrhotite and pentlandite compositions cannot be represented wholly by a binary system, a complete study of the ternary system FeS—NiS—Ni_3S_2 is required.

The low-temperature form of NiS, called millerite, which has a rhombohedral structure, inverts to NiS with hexagonal NiAs structure at 396° C. Above this temperature FeS and NiS are isostructural. When mechanical mixtures of FeS and NiS in the composition range 25 FeS 75 NiS to 85 FeS 15 NiS are heated in closed evacuated silica tubing, pentlandite ($(Fe,Ni)_9S_8$) and an $(Fe,Ni)_{1-x}S$ mix-crystal are formed. Studies on the relation between the pyrrhotite-type $(Fe,Ni)_{1-x}S$ mix-crystals and the contemporaneously formed pentlandites have so far been conducted at temperatures ranging from 950° C down to 500° C.

The CuS—CuSe relationship (Kullerud). Selenium can substitute for sulfur to some extent in most minerals. In many cases where a sulfide mineral is isostructural, or at least very closely related structurally with the corresponding selenide mineral, a complete solid solubility between the two compounds may be anticipated. A study of the relationship of the Se:S ratio in sulfides is a task of importance for our understanding of the geochemistry of selenium and is also of practical value for the mining industry.

CuS (covellite) was prepared from Cu and S in the ratio 1:1 by heating in evacuated, closed silica tubes at temperatures below 230° C. Above this temperature the compound Cu_9S_5 (digenite) was obtained instead of covellite.

CuSe (klockmannite) was prepared from Cu and Se in the ratio 1:1 by the same procedure as described above. This experiment produced crystals of klockmannite, suitable for single-crystal X-ray work. It was found that klockmannite and covellite, although closely related structurally, are not isostructural (see Donnay, below). A homeostructural relationship exists, however, permitting a continuous solid solution, which is now being studied.

The system Cu_2S—CuS (Kullerud). This system includes some of the most important copper sulfide ore minerals. Experiments with compositions varying from Cu_2S to CuS have produced the compounds Cu_2S (chalcocite), Cu_9S_5 (digenite), and CuS (covellite). At temperatures above 425° C, some digenite is always formed regardless of the Cu:S ratio. Digenite crystals well suited for X-ray single-crystal work were grown in a number of runs; single crystals of this mineral had not been grown before. Digenite has a cubic symmetry. Detailed single-crystal X-ray work on this compound is being done by Donnay. The digenite-covellite relationship and the digenite-chalcocite relationship are now being investigated. The digenite structure is stable over a wide range of composition. Experiments are now being run at various temperatures to determine the limits of composition.

The two minerals chalcocite and digenite have been widely confused in literature.

It may well turn out that digenite is the more important ore mineral.

Pyrite (Kullerud, Yoder). The most common sulfide occurring with rock-forming silicates is pyrite, FeS_2. Because of its ubiquitous occurrence, knowledge of its stability field would contribute to an understanding of the conditions of formation of the common rocks. Its synthesis was found to be difficult by previous workers using techniques available at low pressures. Considerable success has been obtained in the synthesis of the hydrous minerals using high water pressures, and it was reasoned that high sulfur pressures might similarly aid the formation of sulfides. The principal difficulty was in obtaining a container which would not react with either the metals or sulfur. Sealed platinum tubes, used in hydrothermal experimentation, were employed because platinum is known to absorb only limited amounts of metals and is believed to form a thin protective sulfide coating. With this technique pyrite has been synthesized under high confining pressures. It will now be possible to determine the P-T stability field of pyrite, as well as that of other sulfides, in a simple, systematic fashion.

The system silver—tellurium (Kracek, Rowland). This system is of interest from three points of view. First, from the point of view of the mineralogist, it is of interest because of the occurrence of three minerals long accepted in the literature; namely, hessite, empressite, and stützite. Recent work by Canadian mineralogists (Thompson, Peacock, Rowland, and Berry) casts doubt on the validity of stützite as a mineral species, and indicates that the one crystal of this mineral now in existence, an original crystal collected by Schrauf in Transylvania, is probably empressite. Empressite itself was synthesized by the Canadian workers. They found that the composition of the artificial crystalline phase analogous to natural empressite can be described as $Ag_{2-x}Te_{1+x}$. This formula also describes the composition of the mineral, which was found to be $Ag_{54.77}Te_{45.26}$ by analysis.

Second, the system is of interest chemically because the three systems of silver with sulfur, selenium, and tellurium, respectively, all have a well-defined compound Ag_2X, where X stands for S, Se, or Te. These three compounds occur in nature as argentite and acanthite, Ag_2S; naumannite, Ag_2Se; and the previously mentioned hessite, Ag_2Te. In a published paper we have discussed the phase relations in the system Ag—S and have shown that the two crystal-crystal transitions in Ag_2S, one at 176.3° to 177.8° C, the other at 586° to 622° C, are both variable in temperature over very narrow composition limits. Similarly, in the system Ag—Te, the compound Ag_2Te is found to have two crystal-crystal transitions, which likewise exhibit temperature variability with composition. A lower transition is found at 105° ± 25° C in the presence of a slight excess of Te, and at 145° ± 2° C in the presence of a slight excess of Ag; for the upper transition the corresponding temperatures are 689° ± 5° and 802° ± 2° C.

These transition-temperature variabilities cause the interest in the system Ag—Te from the third point of view, that of solid-state physics. The orthodox thermodynamic explanation of transition-temperature variability with composition is that the crystalline phase takes up in solid solution one or the other component entering into its composition. Numerous examples are known in which this occurs, but in no previous example have such extreme changes in temperature been observed with very narrow composition ranges as in the Ag—Te system.

From the chemical point of view the system is of further interest because of the occurrence of a second compound, with the unusual chemical formula Ag_5Te_3. This second compound has previously been assigned different chemical formulas, such as AgTe, Ag_3Te_2, Ag_7Te_4, $Ag_{12}Te_7$, and $Ag_{2-x}Te_{1+x}$. In our work the new

formula Ag_5Te_3 has been established by noting the presence or absence of thermal arrests due to (1) the lower transition in Ag_2Te and (2) the eutectic between the compound in question and crystalline Te. Both these arrests had minimal values at the composition Ag_5Te_3. X-ray work (Rowland) shows that Te diffraction lines, on the one hand, and Ag_2Te lines, on the other, are absent at this composition, and that the X-ray pattern is identical with that reported by the Canadian investigators for the mineral empressite. Material of the empressite composition, Ag_5Te_3, exhibits two transitions, the temperatures of which, like those of Ag_2Te, are sensitive to composition. The lower of these transitions is found as a distributed heat effect culminating at about 295° C in the presence of excess Te, and at about 250° C in the presence of Ag_2Te. The upper transition is located at 419° ± 5° C in Te-rich and at 417° ± 2° C in Ag-rich preparations. At 460° ± 5° C the compound Ag_5Te_3 decomposes peritectically into crystals of Ag_2Te and a Te-rich liquid.

In compositions lying between Ag_2Te and Ag the melts are found to form two liquid layers which separate at 881° C; there is a eutectic of Ag_2Te and Ag at 869° C. The melts of Te and Ag_5Te_3 show a eutectic at 353° C.

As was mentioned above, the Canadian mineralogists have thrown doubt on the existence of stützite as a mineral of the composition Ag_4Te, assigned to it by Schrauf. Our own work showed that no compound is formed in the system in the composition range between Ag_2Te and Ag. The experimental data establish the existence of transitions with temperature variability within narrow ranges of composition centered on the phases Ag_2Te and Ag_5Te_3. The novel features of such transitions present aspects not previously discussed in the theory of crystal transitions.

CRYSTALLOGRAPHY

The progress made in crystallography since the discovery of X-ray diffraction as a tool for structure determination has given us a relatively complete understanding of the ordered behavior of matter. It has opened a new era in mineralogy. With the knowledge that silicon always surrounds itself by four oxygens at the corners of a tetrahedron and that these tetrahedra may share only corners (not edges or faces), even the most complicated silicate formulas can now be accounted for.

Yet we have just scratched the surface of our science, enough only to see the paths along which research may open new vistas. The departure of crystals from perfect regularity and, often intimately related to this, the ability of chemically distinct phases to intergrow with each other while preserving many of the characteristics of "single" crystals are much more common than was assumed a few years ago.

Sulfides, selenides, and tellurides (Donnay). In contrast with the situation in silicate chemistry, where the fundamental principles are well enough understood so that one can now profitably study the finer details, relatively little is known about the crystal chemistry of the sulfide group, which comprises some of the most important ore minerals. The chief reason for this is that the chemical bonding varies from nearly pure ionic in certain compounds to strongly polarized, grading into covalent, in others, and finally to semimetallic in a third large group of structures. Even within one compound intermediate types of bond have been found. The presence of intermediate types is evidenced by the physical and chemical properties, some of which are those expected of an ionic structure, whereas others are those of alloys, and still others are characteristic only of sulfide chemistry. In ionic structures, the variation in composition so strikingly illustrated by minerals is due to *substitution* of ions of similar size, not necessarily of identical charge (e.g., plagioclase, $Na_{1-x}Ca_xAl_{1+x}$-

$Si_{3-x}O_8$); in alloys it is frequently due to *addition* of small atoms in the interstices of the structure (e.g., steel, FeC_x). The range of compositions, i.e. the extent of the addition solid solution, is here controlled by the atom-to-electron ratio. In the iron sulfide mineral pyrrhotite a third type of solid solution, that due to *omission,* exists (G. Hägg, 1933). The sulfur atoms form a rigid framework from which iron atoms are randomly missing, so that the formula must be written $Fe_{1-x}S$. Because the experimental procedure used to prove this formula was difficult, relying on X-ray powder patterns and densities of synthetic samples of different compositions, omission solid solution has not been established in any other case, although its existence has been tacitly assumed for several minerals. The principal obstacle to this work in the past has been the absence of single-crystal material. Kullerud, of this Laboratory, has succeeded in synthesizing single crystals, so that we can now hope to make further progress.

We have begun the investigation with the study of a copper sulfide, digenite; a copper selenide, klockmannite; and a silver telluride, empressite (see below). Preliminary results establish the formula $Cu_{9-x}S_5$ for digenite and $Ag_{5-x}Te_3$ for empressite. They show that CuS, covellite, and CuSe, klockmannite, have related but not identical crystal structures; the CuS—CuSe solid solution is not one of simple substitution, but involves the formation of a superstructure.

In the study of the system Cu_2S—CuS, single crystals of digenite were synthesized for the first time (Kullerud). They form octahedra, with rounded faces, 0.3 mm across, occasionally truncated by small cube faces. Runs with starting compositions CuS, Cu_9S_5, and Cu_2S were studied by X rays. Rotation and precession films, taken with CuKα radiation, give the same cell size for single crystals selected from the CuS and the Cu_9S_5 runs, namely, $a=27.71$ Å (± 0.3 per cent). A pseudo repeat $a'=a/5=5.54$ Å is observed, although not very pronounced. The diffraction aspect F*** and probable space group Fm3m are found for both the true cell and the pseudo cell. The most striking feature of the diffraction pattern is the complete absence of streaky reflections, which indicates a perfectly ordered crystal structure. Equally noteworthy are the numerous structural extinctions: (HKL) reflections are observed only if $H=10m\pm L$, $K=10n\pm L$, where m and n are integers. Complete intensity data are being collected for crystal-structure determination. Single crystals from the Cu_2S run proved to be pseudomorphs of orthorhombic chalcocite after digenite.

The specific gravities of several samples taken from the above runs were determined on the Berman balance. Powder patterns were obtained in each case (Kullerud) to check the homogeneity of the sample. The specific gravities are 5.34 for a sample from the CuS run and 5.51 for one from the Cu_9S_5 run. Since the cell size is the same for these two runs (see above), the difference in specific gravity indicates a difference in composition. As is observed in some other sulfides, selenides, and tellurides, the anions must form a rigid framework, which is not affected by the removal of copper atoms. With the ideal formula Cu_9S_5, the highest observed density reported in the literature (5.710, Tularosa district, New Mexico), and the above cell dimensions, 100 formula units must occupy the cell. The 500 sulfur atoms, if placed at the nodes of 125 face-centered pseudo cells, would constitute the expected rigid framework. The calculated compositions are $Cu_{8.24}S_5$ and $Cu_{8.59}S_5$ for the "CuS" and "Cu_9S_5" runs, respectively.

The well-known intergrowths of digenite with hexagonal chalcocite or covellite can now be accounted for: the (111) sulfur layer of digenite forms a hexagonal net with a sulfur-to-sulfur distance equal to $a'\sqrt{2}/2=3.92$ Å, as compared with $a=3.90$ Å for high-temperature chalcocite and $a=3.81$ Å for covellite. The predicted in-

terface is the (111) of digenite and the (0001) of high-chalcocite or covellite.

Single crystals of CuSe (synthetic klockmannite) were prepared by Kullerud. They consist of thin hexagonal plates (0.01 mm thick, 0.3 mm across), with metallic luster. They show forms compatible with holohedral symmetry: 0001, $10\bar{1}0$, $10\bar{1}1$, referred to the known pseudo cell (redetermined as $a'=3.954$ Å, $c=17.25$ Å), which controls the morphology. Rotation patterns about the a axis give the true a repeat: $a=13a'=51.40$ Å. The twelve intermediate layer lines are only about one-tenth as intense as the strong 0, 13th, and 26th layer lines; they show streakiness, which so far has prevented determination of the true space group. The pseudo space group is established as P6/mmc, from diffraction pseudo aspect P**c together with the holohedry suggested by morphology.

Klockmannite has been said to be isostructural with covellite, CuS. Although the similarity of the pseudo cell of klockmannite to the cell of covellite does suggest a *homeo*structural relation, klockmannite cannot be *iso*structural with the accepted covellite structure.

Three-dimensional intensity data are being collected on Kullerud's synthetic klockmannite by means of the integrating precession technique, which yields absorption-corrected as well as integrated intensities. A narrow pinhole (0.3 mm in diameter) was specially built for the purpose, so that the whole X-ray beam can be intercepted by the small crystal plate.

One of the two compounds found in the Ag—Te system (Kracek) is Ag_5Te_3. Its X-ray powder pattern is identical with that of empressite (Kracek and Ksanda). The composition of this mineral, as given in the literature, varies considerably, but is consistently low in silver. Different formulas have been proposed; the most recent one, $Ag_{2-x}Te_{1+x}$ (Thompson, Peacock, Rowland, and Berry, 1951) implies substitution solid solution. Professor L. G. Berry kindly placed at our disposal his synthetic single crystals of known composition Ag_5Te_3. The cell dimensions are redetermined as follows: hexagonal, $a=13.49$ Å, $c=8.47_4$ Å, $V=1334.7$ Å^3, all ± 0.3 per cent, confirming the results of Thompson *et al.* The diffraction aspect is P***, but a pronounced pseudo aspect $P6_3$** is found (all reflections 00L with L odd are missing except 0003). The calculated specific gravity is 8.03, in agreement with the observed value 8.05 ± 0.10 (Berman balance). Synthetic powdery Ag_5Te_3 (prepared by Kracek) yielded X-ray data which, analyzed (Rowland) by the least-squares method, gave the same cell dimensions as Berry's material.

The cell dimensions of empressite were obtained by Thompson *et al.* from the powder pattern of a specimen from the type locality (analyzed by R. N. Williams: Ag 54.77, Te 45.26, total 100.03; corresponding to $Ag_{4.55}Te_3$). They are identical with those of synthetic pure Ag_5Te_3. It is therefore concluded that empressite has the same crystal structure as Ag_5Te_3. The predicted specific gravity of $Ag_{4.55}Te_3$ is 8.05 for a substitution solid solution, 8.48 for a solid solution due to addition of tellurium, and 7.58 for one resulting from omission of silver. The observed specific gravity, 7.61 (Thompson *et al.*), proves the last-mentioned hypothesis. The formula of empressite must therefore be written $Ag_{5-x}Te_3$.

Omission solid solution was to be expected on structural grounds: (1) The tellurium:silver radius ratio is not small enough for tellurium to be interstitial. (2) The two elements are too different in electronegativity to substitute for each other. (3) Only omission solid solution can account for the constancy of cell dimensions with changes in composition. The tellurium atoms must form a rigid framework, which controls the size of the cell; the absence of silver atoms results in holes in the structure but does not affect the positions of the tellurium atoms.

ANHYDROUS SILICATE RESEARCH

A Review of the Present Status

During the past fifty years systematic studies of the melting, crystallization, and stability relations in the principal systems of rock-forming oxides have been conducted at the Geophysical Laboratory. The results of these phase-equilibrium investigations have provided a quantitative basis for inquiry into the origins of igneous rocks and many other geological processes. This section reviews the present status of these studies.

An examination of the average composition of igneous rocks, given in table 4,

TABLE 4

Average composition of igneous rocks

Oxide	Percentage
Silica (SiO_2)	59.12
Alumina (Al_2O_3)	15.34
Ferric (Fe_2O_3)	3.08
Ferrous (FeO)	3.80
Lime (CaO)	5.08
Soda (Na_2O)	3.84
Magnesia (MgO)	3.49
Potassia (K_2O)	3.13
Water (H_2O)	1.15
Titania (TiO_2)	1.05
Phosphoric (P_2O_5)	0.30
Manganous (MnO)	0.12
All others	0.50
Total	100.00

shows that silica and alumina are the most abundant of the rock-forming oxides in the crust of the earth. Fenner (1913) determined the stability relations of the several forms of silica, and Greig (1927) determined the melting point of cristobalite. Bowen and Greig (1924) studied the system Al_2O_3—SiO_2. Several of the fundamental ternary systems of silica and alumina with another important rock-forming oxide have been reported as follows: CaO—Al_2O_3—SiO_2 (Rankin and Wright, 1915), MgO—Al_2O_3—SiO_2 (Rankin and Merwin, 1918), and FeO—Al_2O_3—SiO_2 (Schairer and Yagi, 1952).

The systems Na_2O—Al_2O_3—SiO_2, K_2O—Al_2O_3—SiO_2, and $NaAlSiO_4$—$KAlSiO_4$—SiO_2 (Schairer, Bowen). Because of the widespread occurrence in rocks of the alkali aluminosilicates, particularly the alkali feldspars, a knowledge of the systems Na_2O—Al_2O_3—SiO_2 and K_2O—Al_2O_3—SiO_2 is of extreme importance and interest. The principal components of natural feldspars are soda feldspar ($Na_2O \cdot Al_2O_3 \cdot 6SiO_2$ or $NaAlSi_3O_8$), potash feldspar ($K_2O \cdot Al_2O_3 \cdot 6SiO_2$ or $KAlSi_3O_8$), and lime feldspar ($CaO \cdot Al_2O_3 \cdot 2SiO_2$ or $CaAl_2Si_2O_8$). Bowen (1913) determined the liquidus and solidus temperatures for the plagioclase system and showed that there is an unbroken series of solid solutions between the soda and lime feldspars at high temperatures. At that time it was not possible to crystallize the pure soda feldspar from the extremely viscous glass of its own composition. Morey and Bowen (1922) showed that potash feldspar melts incongruently at about 1170° C to the feldspathoid leucite ($K_2O \cdot Al_2O_3 \cdot 4SiO_2$ or $KAlSi_2O_6$) and a viscous, more siliceous, complementary liquid, and that it becomes completely liquid only at about 1530° C. Thus it became apparent that the experimental determination of the melting relations of potash feldspar in the system leucite—silica and in the more comprehensive system K_2O—Al_2O_3—SiO_2 would be difficult owing to the high melting temperature of pure leucite and to the extreme viscosity of melts in the composition region between potash feldspar and silica, which would make crystallization difficult or perhaps impossible.

Feldspars occur with quartz in the granitic rocks and with the feldspathoids leucite or nepheline ($Na_2O \cdot Al_2O_3 \cdot 2SiO_2$ or $NaAlSiO_4$), or both; or rarely with kalsilite ($K_2O \cdot Al_2O_3 \cdot 2SiO_2$ or $KAlSiO_4$); or with kaliophilite, another polymorph of $KAlSiO_4$, in the alkaline rocks. It should be apparent that a knowledge of the melting relations in the ternary systems Na_2O—Al_2O_3—SiO_2 and K_2O—Al_2O_3—SiO_2 and

in the plane $NaAlSiO_4$—$KAlSiO_4$—SiO_2 in the quaternary system Na_2O—K_2O—Al_2O_3—SiO_2 is essential if we are to interpret the complex crystallization relations in rock-forming magmas during the late stages of crystallization.

During the years between 1929 and 1941 Schairer and Bowen determined the phase-equilibrium relations, at or slightly below temperatures where a liquid phase was present, in the ternary systems Na_2O—Al_2O_3—SiO_2 and K_2O—Al_2O_3—SiO_2. Concurrently with the studies of these two systems, the melting relations in $NaAlSiO_4$—$KAlSiO_4$—SiO_2 were studied by these same investigators. A preliminary report on this last system was published (Schairer and Bowen, 1935). More recently the data on the alkali feldspar join $NaAlSi_3O_8$—$KAlSi_3O_8$ were published (Schairer, 1950), and a more complete equilibrium diagram for $NaAlSiO_4$—$KAlSiO_4$—SiO_2 was presented without, however, the data on which it was based. It is hoped eventually to publish the very large amount of data obtained since 1929 on this last system. Before proceeding with such a presentation it seemed desirable, however, to record first of all the complete results on the systems K_2O—Al_2O_3—SiO_2 and Na_2O—Al_2O_3—SiO_2.

In order to locate the liquidus surfaces in K_2O—Al_2O_3—SiO_2 and the fields of the primary phases cristobalite, tridymite, quartz, mullite, corundum, potash feldspar, leucite, hexagonal $KAlSiO_4$, orthorhombic $KAlSiO_4$, potassium tetrasilicate, and potassium disilicate, Schairer and Bowen prepared and studied 383 different synthetic melts by the method of quenching. The temperatures and compositions of ten binary and eleven ternary invariant points within the ternary system were located. In the system Na_2O—Al_2O_3—SiO_2, the portion Na_2SiO_3—$Na_2Si_2O_5$—$NaAlSiO_4$ was studied by Tilley (1933), working with Bowen and Schairer in 1931. Greig and Barth (1938) determined the relations in the binary system $NaAlSi_3O_8$—$NaAlSiO_4$. In order to locate the liquidus surfaces in Na_2O—Al_2O_3—SiO_2, Schairer and Bowen prepared and studied 340 different synthetic melts and located the fields of cristobalite, tridymite, quartz, albite, mullite, nepheline, carnegieite, corundum, sodium orthosilicate, sodium metasilicate, and sodium disilicate, and the many binary and ternary invariant points within the system.

Some of the very numerous data on K_2O—Al_2O_3—SiO_2 and Na_2O—Al_2O_3—SiO_2 were assembled in 1941, but their publication was interrupted by the war. Because of the general usefulness of the results in petrology and silicate technology, the final diagrams for these two systems were made available (Schairer and Bowen, 1947), but publication of the large quantity of data on which the diagrams were based and a full discussion of the experimental methods, detailed results, and some of the applications was deferred. Two long manuscripts have been prepared during this past year and are now in press in the *American Journal of Science.* This brings to a successful conclusion our studies of two more of the fundamental ternary systems of important rock-forming oxides, and prepares the way for the presentation of our data on $NaAlSiO_4$—$KAlSiO_4$—SiO_2.

The quaternary system K_2O—MgO—Al_2O_3—SiO_2 (Schairer). The phase-equilibrium relations in this system were determined with many objects in view, the most important of which were (1) to ascertain the mutual stability relations of the rock-forming alkali aluminosilicates, potash feldspar, leucite, and $KAlSiO_4$ in its several forms, with forsterite, pyroxenes, spinel, periclase, cordierite, corundum, and mullite; (2) to determine the direction of change of composition of quaternary liquids during crystallization and the goal toward which they proceed during fractional crystallization; and (3) to provide reliable data on a series of dry melts to which water could be added later in order to study the stability relations of phlogo-

pite, a group end member of the biotite micas, which are widespread mineral constituents of many igneous and metamorphic rocks.

Because no data were available on the system K_2O—MgO—SiO_2, one of the fundamental ternary systems of rock-forming oxides (see table 4) and a limiting ternary system of the quaternary system, one of the first necessary steps was to obtain data for this ternary system, which was studied by E. W. Roedder at the Geophysical Laboratory during the year 1948–1949 (Roedder, 1951).

Concomitantly with the study of the system K_2O—MgO—SiO_2, a series of triangular joins within the quaternary system was investigated. The results on five of these joins have been published (Schairer, 1954). They establish the relations in two large volumes within the regular tetrahedron used to represent the quaternary system. These volumes are leucite—corundum—spinel—silica and leucite—forsterite—spinel—silica. The significance of the data was presented in Year Book No. 51, 1951–1952 (pp. 51–52). Some of the mixtures in these two volumes are rather close in composition to rock magmas, and it is significant that the goal toward which crystallization proceeds during fractional crystallization is a granite, and that crystallization proceeds toward a granitic composition even if the magmas are contaminated by, and wholly or partially assimilate, basic igneous rocks such as peridotites or dunites, or highly aluminous sediments.

During this past year the results on the binary system leucite—spinel and the joins leucite—corundum—spinel and leucite—forsterite—spinel, two ternary systems within the quaternary system, were published (Schairer, 1955). Eight additional joins have been studied and the data have been analyzed during this past year. Our experimental studies of the quaternary system are substantially completed, but the difficult task of presenting the large amount of data in a lucid manner still lies ahead.

The quaternary system Na_2O—Al_2O_3—Fe_2O_3—SiO_2 (Schairer). Some years ago the incongruent nature of the melting of the pyroxene acmite ($Na_2O \cdot Fe_2O_3 \cdot 4SiO_2$) was determined (Bowen and Schairer, 1929) and the relations in the system Na_2SiO_3—Fe_2O_3—SiO_2 were studied (Bowen, Schairer, and Willems, 1930). Recently these studies were extended into the quaternary system Na_2O—Al_2O_3—Fe_2O_3—SiO_2 in order to study the pyroxenes between acmite and jadeite ($Na_2O \cdot Al_2O_3 \cdot 4SiO_2$) and the relations between the pyroxenes and the soda feldspar albite ($Na_2O \cdot Al_2O_3 \cdot 6SiO_2$) and the feldspathoid nepheline.

Five joins have been completed, as follows: (1) ($Na_2O \cdot 4SiO_2$)—jadeite—acmite, (2) nepheline—acmite—silica, (3) nepheline—acmite—sodium disilicate, (4) sodium disilicate—acmite—albite, and (5) nepheline—acmite—$5Na_2O \cdot Fe_2O_3 \cdot 8SiO_2$. During the past year these data were analyzed, and they provide considerable information on limited solid solutions in nepheline and in albite and on the locations of, and phase assemblages at, many of the quaternary invariant points. The results on these five joins are a substantial contribution to our knowledge of the quaternary system and the late stages in the crystallization of iron-rich magmas.

Combination of early-crystallizing minerals with late-crystallizing alkali aluminosilicates (Schairer, Bowen). The composition of residual liquids from the fractional crystallization of rock magmas is of great petrological interest. Bowen (1937) has called the system $NaAlSiO_4$—$KAlSiO_4$—SiO_2 "petrogeny's residua system," and has shown that the association of alkaline lavas of the region of the Great Rift Valley in Africa has those chemical characters of residual liquids that one is led to expect from experimental studies. From a study of a number of relatively simple systems combining one of the early-crystallizing minerals in rocks with late-crystallizing alkali aluminosilicates, we may confidently

reach some general conclusions regarding the crystallization of complex mixtures. Such a series of simple systems has been under study at the Geophysical Laboratory for many years.

The relations of these simple systems to "petrogeny's residua system" are shown in figure 15. Petrographic evidence indicates that olivine is one of the earliest minerals to crystallize from rocks. Olivines are solid solutions of forsterite ($2MgO \cdot SiO_2$ or Mg_2SiO_4) and fayalite ($2FeO \cdot SiO_2$ or Fe_2SiO_4). One of the next minerals to tional crystallization in complex systems approach the low-temperature trough in "petrogeny's residua system."

The status of the simple systems shown in figure 15 is given here: (1) Leucite—forsterite—silica, published by Schairer (1954). (2) Leucite—fayalite—silica, studied by Roedder at the University of Utah and published (Roedder, 1951). (3) Leucite—diopside—silica, published by Schairer and Bowen (1938). (4) Leucite—anorthite—silica, published by Schairer and Bowen (1947). (5) Nepheline—forsterite—silica.

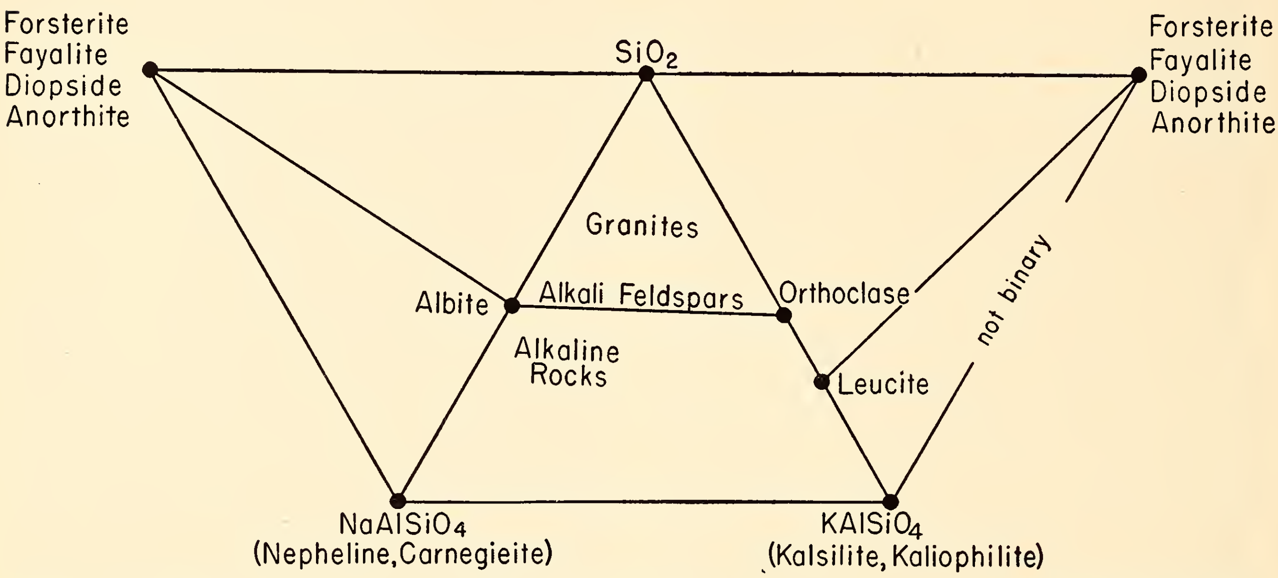

Fig. 15. Diagram showing interrelation of systems involving both early- and late-crystallizing minerals. The system $NaAlSiO_4$—$KAlSiO_4$—SiO_2 is "petrogeny's residua system."

crystallize is a pyroxene. Diopside ($CaO \cdot MgO \cdot 2SiO_2$ or $CaSiO_3 \cdot MgSiO_3$) is a simple pyroxene. One of the next minerals to crystallize is the lime feldspar anorthite ($CaO \cdot Al_2O_3 \cdot 2SiO_2$ or $CaAl_2Si_2O_8$) or a high-lime plagioclase. By combining the four early-crystallizing minerals forsterite, fayalite, diopside, and anorthite with potash aluminosilicates and also with soda aluminosilicates, we get a series of simple systems, which have been investigated. All these systems yield residual liquids from crystallization, which are very rich in alkali aluminosilicates and lead us to the conclusion that residual liquids from frac- A large part of this system has been studied by Greig, whose results have not yet been published. (6) Nepheline—fayalite—silica, published by Bowen and Schairer (1938). (7) Nepheline—diopside—silica. The portion nepheline—diopside has been studied by Schairer and Yagi, and nepheline—diopside—silica by Schairer. The results have not yet been published. (8) Nepheline—anorthite—silica. This may be divided into two portions, nepheline—albite—anorthite and albite—anorthite—silica. The data for both portions are complete, and it is expected that two manuscripts will be prepared for publication.

ANHYDROUS MINERAL—WATER SYSTEMS

The action of hot water on some feldspars (Morey, Chen). Igneous rocks such as the granites are slowly decomposed in nature by the action of water, often containing dissolved material such as carbonic acid, under subcrustal or atmospheric conditions; and sand, clays, laterites, and soils are results of such processes. It seemed of interest to pass hot water over feldspars under controlled conditions, to analyze the water frequently during the course of the experiment, to see if the nature of the reaction changed, to find the amount and composition of the material dissolved, and to examine the residual material at the end of the experiment.

Orthoclase, $K_2O \cdot Al_2O_3 \cdot 6SiO_2$, in size to pass a ¼-inch screen and hold on an 8-mesh screen, was placed in a high-pressure vessel with openings at each end, contained in a furnace which held the temperature of the vessel at 350° C. Water at 5000 psi was passed over the orthoclase and analyzed. The run lasted 103 days, and a total of 194,432 g of water was collected and analyzed in 45 consecutive samples. The total amount of material dissolved was 52.1514 g, or 268 parts per million of water.[3] The molecular ratio of the dissolved materials was $K_2O:Al_2O_3:SiO_2 =$ 1.11:1:6.70, instead of the theoretical 1:1:6. This corresponds to 47.2593 g orthoclase, or 91 per cent, together with 0.858 g excess K_2O and 4.0471 g SiO_2, giving a mol ratio for $K_2O:SiO_2$ of 1:6.3. Examination of the residue in the bomb showed it to consist of some original orthoclase, coated with muscovite mica, $KAl_2(AlSi_3O_{10})(OH)_2$, in excellent crystals, and much boehmite, $Al_2O_3 \cdot H_2O$, a mineral common in the bauxite deposits in France. The rate of the reaction was essentially constant throughout the run, although there may have been a slightly more rapid initial decomposition before the orthoclase grains became covered with muscovite.

Three series of runs have been made with albite, $Na_2O \cdot Al_2O_3 \cdot 6SiO_2$. The first series was under conditions similar to those used with orthoclase, 350° C and 5000 psi, and coarse granular material. This run was terminated in 38 days by the crystallization of the mineral analcite, $Na_2O \cdot Al_2O_3 \cdot 4SiO_2 \cdot 2H_2O$, in the upper part of the bomb and the exit tube. The total weight of solution obtained was 78.005 g, and the total weight of dissolved material was 24.7915 g, or 316 parts per million. The molecular ratio of the dissolved material was $Na_2O:Al_2O_3:SiO_2 = 1.05:1:6.72$ instead of the theoretical 1:1:6. This corresponds to 22.7917 g, or 92 per cent, albite, together with excess of both Na_2O and SiO_2. Examination of the residue in the bomb showed it to consist of some original albite, with a micaceous surface coating. This micaceous coating was, surprisingly, composed largely of the potash mica muscovite. The original albite used contained a small amount of potassium oxide, and calculation showed that most of it probably had been retained as muscovite. This reaction has interesting implications with regard to the common sericitic alteration of plagioclase. There was also present some of the soda mica paragonite, $NaAl_2(AlSi_3O_{10})(OH)_2$, analcite, and much boehmite, $Al_2O_3 \cdot H_2O$. Under these conditions both the common feldspars are largely transported as such; some decomposition occurs, with formation of residual boehmite and some mica.

Similar runs have been made at lower temperatures. In these runs, the albite is graded between 8 and 25 meshes per inch, to increase the effective surface. At 200°, 2000 psi, 279 liters of water dissolved 14.6594 g of material, corresponding to 52 parts per million. The dissolved material contained Na_2O, Al_2O_3, and SiO_2 in the molecular ratio 1.72:1:8.86, instead of the theoretical ratio 1:1:6; and the material

[3] It is to be emphasized that this is not a solubility, but a measure of a rate of decomposition under the given conditions.

left in the bomb consisted of unaltered albite, boehmite, and probably kaolinite. No analcite was found at this temperature. Another series of runs was made at 100° and the city water pressure, about 40 psi. The total weight of dissolved material corresponded to about 6.4 parts per million. The solution indicated a larger amount of decomposition of the albite by water, and the altered residue consisted of boehmite and kaolinite.

The system forsterite—anorthite—diopside—water (Yoder). The system forsterite—anorthite—diopside—water is being investigated at 5000 bars. This system closely approaches the mineralogy of a basalt, and studies of it will contribute a large body of fundamental data to the problem of the origin of the various types of basalt. When the four-component system is completed, it will be possible to examine the melting behavior of the natural rock itself with the insight gained from the synthetic system. It is anticipated that a comprehensive analysis of the basalt problem, based on these studies, will be prepared for publication.

Practically all igneous rocks are now classified on the basis of the composition of their feldspars, and therefore the feldspars warrant intensive study. Successful studies have been made at the Laboratory in the solidus and liquidus regions of the anorthite—albite—orthoclase system, which encompasses all the common feldspars. The subsolidus region presents many complications which have not been amenable to investigation in the dry way because of the sluggish nature of the transitions. These complexities provide the geologist with unique clues to the thermal history of the rock in which the feldspars occur. The hydrothermal study by Bowen and Tuttle of a portion of the fundamental system proved exceptionally rewarding, and preliminary work indicates that the entire system can be successfully attacked in a similar way. In another section (above), J. R. Smith and Yoder indicate how the thermal state of a plagioclase may be defined if the composition is known. With this technique it may now be possible to investigate the albite—anorthite—water system in the subsolidus region.

THE AGE OF ROCKS AND MINERALS

(A co-operative program of the Geophysical Laboratory and the Department of Terrestrial Magnetism of the Carnegie Institution of Washington)

Critical comparison of dating schemes (Davis, Aldrich,[1] Tilton,[1] Wetherill[1]). The dating of great cosmic and terrestrial events is one of the most significant questions of our time. Recent studies are giving more consistent estimates of the age of the universe and the dates of important geological events than have previously been available. In this work a variety of radioactive decay schemes have been employed, and perhaps the most needed information now is a measure of the reliability of the physical constants on which the methods depend.

The radioactive decay systems which lend themselves to age measurements are uranium^{238}-lead^{206}, uranium^{235}-lead^{207}, thorium^{232}-lead^{208}, rubidium^{87}-strontium^{87}, potassium^{40}-argon^{40}, and potassium^{40}-calcium^{40}. An age may also be determined from the ratio of lead^{207} to lead^{206} as a result of the difference between the decay rates of the two uranium isotopes. All these methods are being employed, potassium-calcium being in an early stage of use as compared with the others.

The initial goal of the program has been to compare critically the ages obtained from the different decay schemes when applied to individual and associated minerals, with the aim of finding the most favorable conditions for obtaining a significant measure of the absolute age. These

[1] Department of Terrestrial Magnetism, Carnegie Institution of Washington.

conditions involve the decay scheme(s) to be measured in the mineral(s) which offer the best chance of success under circumstances which can be recognized before starting a determination.

The essential requirements which must be met in a satisfactory radioactivity time clock are: The rate of radioactive decay must be known; the parent and daughter elements must be determined quantitatively with sufficient accuracy; the rock or mineral must have crystallized without incorporating large amounts of daughter element; and there must have been no appreciable gain or loss of either parent or daughter during the geologic lifetime by processes other than radioactive decay. The work this year has been devoted to studying whether these criteria are satisfied in a group of associated minerals.

Last year it was reported that, in general, for a given mineral or mineral association Th-Pb^{208} ages were lowest; U^{238}-Pb^{206}, U^{235}-Pb^{207}, and Pb^{207}-Pb^{206} were next; the highest ages were indicated by Rb-Sr. The very high ages obtained by the last method were not supported by the results from other decay systems.

During the past year numerous data from the K-A decay have made the higher ages more credible. Samples from new locations have been analyzed, so that comparisons can now be made at ten places. One locality has been studied in great detail.

The results of analyses made during the past year are incorporated in tables 5 to 9. These tables also include some of the data previously reported, so that comparisons can be made for a single mineral, from mineral to mineral, at each locality, and by each of several decay systems.

The addition of many ages based on the K-A decay during the past year has provided another base of comparison. The K-A method is applicable to the same minerals as is Rb-Sr, namely the micas lepidolite, muscovite, and biotite, and the potassium feldspars, and will probably be applicable to a still wider variety of minerals. The potassium determinations are being made by both isotope dilution and flame photometry.

TABLE 5

Comparison of A^{40}/K^{40} ratios of feldspars and micas from the same rock

Locality	Rock type	A^{40}/K^{40} Feldspar	A^{40}/K^{40} Mica
Quartz Creek, Colo.	Granite	0.0725	0.107
Uncompahgre, Colo.	Granite	.0709	.109
Cape Town, S. Africa	Granite	.0105	.0337
Quartz Creek, Colo.	Pegmatite	.0590	.0974
Black Hills, S. D.	Pegmatite	.0862	.118
Jakkalswater, S. Africa	Pegmatite	.0359	.0695
Wilberforce, Ont.	Pegmatite	0.0614	0.0695

In order to test the K-A method with respect to the criteria already listed, the ratio of radiogenic argon to potassium has been measured in micas and feldspars separated from the same rock. The ratios should be the same for the two minerals if argon does not escape from the crystals. Table 5 gives the results of these measurements.

The feldspars are seen to have a lower A^{40}/K^{40} ratio than the micas in every case. With the exception of the feldspar from the Cape granite, which was partially kaolinized, all the samples were fresh. In the Quartz Creek sample, the flakes of mica were intergrown with the feldspar used in the determination. The cause of the dif-

ference in ratio is not apparent. A comparison of these results with Rb-Sr determinations on the same samples and with U-Pb and Th-Pb determinations on minerals from the same rock (table 6) indicates that the argon age calculated from the mica probably is closer to the true age than that calculated from the feldspar.

The ratios given do not involve the requirement that the rate of radioactive decay be known, but the ages do. From measurements of specific activities the decay constants for the uranium isotopes and thorium are thought to be well known, but the values for potassium and rubidium are most certainly not well established. Comparison of K-A and Rb-Sr ages with reliable uraninite ages should at least indicate the order of magnitude and the direction of the uncertainties in the decay constants. (A reliable uraninite is defined for this purpose as a sample which shows agreement between the U^{238}-Pb^{206} and U^{235}-Pb^{207} ages.) Table 7 contains two such comparisons, at the Ingersoll Mine in the Black Hills and at the Fission Mine in Ontario. These results, taken in conjunction with those shown for the Brown Derby Mine in table 8, show that Rb-Sr ages are about 20 per cent higher than U-Pb ages and that K-A ages are about the same as U-Pb. This indicates that the values used here for the branching ratio (0.10) and decay constant (5.59×10^{-10} yr^{-1}) for potassium are nearly correct (within 10 to 15 per cent). The consistently higher age values for Rb-Sr may be explained by a decay constant of Rb^{87} (1.13×10^{-11} yr^{-1}) too low by 15 to 30 per cent. This value will be used, however, until a better one is determined.

Table 8 presents the results of an extensive study of one pegmatite locality. The difficulties of applying each of the five decay schemes directly to such systems of minerals are evident from the anomalous results for microlite and monazite. Clearly, Rb-Sr and K-A ages are uniform and reproducible for the micas. The results obtained are most compatible with an age of 1400 ± 150 million years for the pegmatite at the Brown Derby Mine and for the Quartz Creek granite from which the pegmatite appears to have been derived. The granite values appear in table 6.

In furtherance of the age studies, an evaluation has been made of the reliability of the mineral zircon as an age indicator. Zircon is used for the so-called alpha-lead method by several laboratories. Age measurements, including isotopic analyses of the lead, have been made on seven sam-

TABLE 6

AGES OF MINERALS FROM GRANITES

Locality	Mineral	Apparent age (million years)					
		U^{238}-Pb^{206}	U^{235}-Pb^{207}	Pb^{207}-Pb^{206}	Th-Pb^{208}	K-A	Rb-Sr
Cape Town, S. Africa	Zircon	330	355	525	237	...	...
	Biotite	...	...	...	...	560	820
	Potassium feldspar *	...	...	...	...	200	...
Bagdad, Ariz.	Zircon	630	770	1210	270	...	...
	Muscovite	...	...	...	...	1480	1750
Uncompahgre, Colo.	Biotite and xenotime	...	...	1650	...	1410	1650
	Potassium feldspar	...	...	...	...	1030	...
Quartz Creek, Colo.	Zircon	930	1130	1540	515	...	...
	Biotite	...	...	...	...	1380	1620
	Potassium feldspar	...	...	...	...	1040	1820

* Kaolinized.

TABLE 7

Ages of minerals from various localities

Locality	Mineral	Apparent age (million years)					
		U^{238}-Pb^{206}	U^{235}-Pb^{207}	Pb^{207}-Pb^{206}	Th-Pb^{208}	K-A	Rb-Sr
Bikita, S. Rhodesia	Lepidolite	....	....	....	....	2570	3200
(Ebonite Claim, S. Rhodesia	Monazite	2640	2670	2690	2640	....	....)*
Bonneville, Wyo.	Lepidolite	....	....	....	....	2390	3050
Bagdad, Ariz.	Lepidolite	....	....	....	....	1500	1900
Ingersoll Mine, Black Hills, S. D.	Lepidolite	....	....	....	....	1500	2080 2050 2025
	Lepidolite	....	....	....	....	....	1890
	Muscovite	....	....	....	....	1690	2130
	Microcline	....	....	....	....	1210	1970
	Uraninite	1580	1600	1630	1440	....	....
Harding Mine, Dixon, N. M.	Microlite	916	996	1180	....	....	....
	Lepidolite	....	....	....	....	....	1590
	Muscovite	....	....	....	....	....	1560
Fission Mine, Wilberforce, Ont.	Biotite	....	....	....	....	1015	1210
	Antiperthite	....	....	....	....	925	....
	(Uraninite	1077	1050	1035	983	....	....)†
Houtenbek, S. Africa	Monazite	930	1400	1230	940	....	....
Jakkalswater, S. Africa	Muscovite	....	....	....	....	1015	1170

* Holmes (recalculated).
† Nier.

TABLE 8

Ages of minerals from Brown Derby Mine, Quartz Creek, Colorado

Mineral	Apparent age (million years)	
	K-A	Rb-Sr
Lepidolite (microlite zone)	1460	1830
Microcline	880	1590
Muscovite (from microcline)	1300	1680
Lepidolite (coarse in spar)	1380	1750
Lepidolite (fine)	....	1900
Lepidolite (coarse)	....	1730
Lepidolite (white)	1400	1690
Lepidolite (medium)	....	1750

	U^{238}-Pb^{206}	U^{235}-Pb^{207}	Pb^{207}-Pb^{206}	Th-Pb^{208}
Microlite	915	1050	1350	...
Monazite	1590	1410	1170	995

ples. These are presented in table 9. Where discrepancies occurred among the various ages for a single sample (in five out of seven cases), the Pb-Pb age is believed to be the most nearly correct, since it gives the best correlation with K-A and corrected Rb-Sr ages on other minerals from the same rock. If this is true, the ages measured by the alpha activity–total lead method, which closely resemble the U^{238}-Pb^{206} ages, are incorrect for five of the analyzed zircons.

Future work will include experiments aimed at explaining the various discrepancies, such as a laboratory investigation of the mechanism of possible loss of daughter or gain of parent elements, which must be responsible for the low K-A, U-Pb, and Th-Pb ages. This investigation will include the effect of heat and environment on the structure of radioactive minerals, with analysis before and after treatment. Further reliable ages will be sought for uraninites and other radioactive minerals.

TABLE 9

AGE MEASUREMENTS ON ZIRCONS

LOCALITY	SIZE	APPARENT AGE (MILLION YEARS)			
		U^{238}-Pb^{206}	U^{235}-Pb^{207}	Pb^{207}-Pb^{206}	Th-Pb^{208}
Tory Hill, Ont.	1–2 mm	1030	1055	1090	390
	—200 mesh	940	960	1015	...
Cape Town, S. Africa	—200 mesh	330	355	525	237
Bagdad, Ariz.	—200 mesh	630	770	1210	270
Quartz Creek, Colo.	—200 mesh	930	1130	1540	515
Ceylon	2–3 cm	540	544	555	538
Natural Bridge, N. Y.	2–3 cm	1025	1065	1140	...

MISCELLANEOUS ADMINISTRATION

Petrologists' Club. The Laboratory was host to the Petrologists' Club during its 1954–1955 season. The five meetings held were attended by as many as one hundred members and visitors. Attendance by the younger members of the profession, as well as by students of related basic sciences, was encouraged. The underlying theme of the annual program was a review of the major rock types. The major developments in recent years have necessitated a reorientation of ideas concerning the genesis of rocks, and the Club provided an opportunity to hear the leaders on the specific problems. Discussion was enthusiastic and rewarding.

The following papers were presented:

"Nepheline syenites," by C. E. Tilley (Cambridge University).

"Tholeiites and basalts," by A. C. Waters (Johns Hopkins University).

"Occurrence and chemistry of rhyolites," by R. L. Smith (U. S. Geological Survey).

"Mineralogy of rhyolites and the welded tuff problem," by F. R. Boyd (Geophysical Laboratory).

"Silicate-carbonate-sulfide rocks in the Bear Paw Mountains," by W. Pecora (U. S. Geological Survey).

"Andesites," by C. Anderson (U. S. Geological Survey).

The Club will be directed in the 1955–1956 season by F. R. Boyd, succeeding H. S. Yoder, who has served four terms.

Seminars. The Laboratory has conducted a weekly series of seminars, with papers presented largely by staff members and concerned mainly with discussions of work in progress. Several talks were presented by outside speakers. These included the following:

"Potassium-argon age determinations," by G. W. Wetherill (Department of Terrestrial Magnetism).

"Crystal-energetic aspects of hydrated solids," "Metamorphic phases," "Plastic flow gneisses," and "Pegmatites," by H. Ramberg (University of Chicago).

"Basalts," by C. E. Tilley (Cambridge University).

"Compositional variation in beryl," by W. T. Schaller (U. S. Geological Survey).

"Age determinations in the vicinity of the Brown Derby Mine," by L. T. Aldrich (Department of Terrestrial Magnetism).

"Thermal conductivity measurements at high pressure," by S. Clark (Harvard University).

"Chloritoid," by L. B. Halferdahl (Johns Hopkins University).

"Migmatites, Northern Cascades, Washington," by C. A. Hopson (Johns Hopkins University).

"Silurian and Devonian rocks of Acadia," by A. Boucot (U. S. Geological Survey).

"Some uranium oxide systems," by L. E. J. Roberts (University of California).

"Structure of the feldspars," by E. Radoslovich (Pennsylvania State University).

"The isolation of organic compounds from lake sediments," by J. R. Vallentyne (Queen's University).

"The use of neutron diffraction in the study of crystal structure," by V. Vand (Pennsylvania State University).

"Chibougamau," by G. Allard (Johns Hopkins University).

"Application of thermodynamics to geological problems," "Thermodynamics of nonideal silicate solutions," and "Thermodynamic conditions for stability and geological applications," by G. J. F. MacDonald (Massachusetts Institute of Technology).

Lectures. During the report year staff members were invited to present lectures as follows:

P. H. Abelson lectured at the annual open meeting of the Howard University chapter of Sigma Pi Sigma National Physics Society, and at a Symposium on Biogenesis at the Polytechnic Institute of Brooklyn.

F. Chayes served as Visiting Professor in the Division of Geological Sciences, California Institute of Technology, and was in residence on the campus from January 1 to mid-March, 1955. During this period he lectured regularly before the graduate seminar in petrology.

W. S. MacKenzie lectured at the Mineralogists Club of the District of Columbia.

G. W. Morey gave a series of three lectures at the E. I. DuPont de Nemours and Company Experimental Station, Wilmington, Delaware. He also addressed a Symposium on Glass at Alfred University.

J. F. Schairer gave a series of lectures before a group of sections of the American Chemical Society at East Lansing, Kalamazoo, and Ann Arbor, Michigan, and Toledo, Ohio. He also addressed the Geology Department of the Johns Hopkins University.

H. S. Yoder lectured at the Columbia University Bicentennial Symposium on the Crust of the Earth; Shell Development Company; Journal Club of the Department of Geology, Johns Hopkins University; and Applied Physics Laboratory, Johns Hopkins University.

The "Summary of Published Work" below briefly describes the papers published in scientific journals during the report year. In addition, the following papers are now prepared for publication: F. Chayes, "Modal composition of two facies of the Carnmenellis granite"; F. Chayes, "The Holmes effect and the lower limit of modal analysis"; G. Donnay, J. D. H. Donnay, and V. J. Hurst, "Precession goniometry to identify neighboring twins"; V. J. Hurst, J. D. H. Donnay, and G. Donnay, "Staurolite twinning"; G. Kullerud, P. Padget, and F. M. Vokes, "The temperature of deposition of sphalerite-bearing ores in the Caledonides of northern Norway"; W. S. MacKenzie, "The orientation of the pericline twin lamellae in triclinic alkali feldspars"; W. S. MacKenzie and J. V. Smith, "The alkali feldspars. I. Orthoclase-microperthites"; W. S. MacKenzie and J. V. Smith, "The alkali feldspars. III. An optical and X-ray study of high-temperature feldspars"; G. W. Morey, F. R. Boyd, Jr., J. L. England, and W. T. Chen, "The system $NaPO_3$—$Na_4P_2O_7$—$K_4P_2O_7$—KPO_3"; J. F. Schairer, "Heterogeneous equilibria and phase diagrams"; J. F. Schairer and N. L. Bowen, "The system Na_2O—Al_2O_3—SiO_2"; J. F. Schairer and N. L. Bowen, "The system K_2O—Al_2O_3—SiO_2"; J. V. Smith, "The powder patterns and lattice parameters of plagioclase feldspars. I. The soda-rich plagioclases"; J. V. Smith and W. S. MacKenzie, "The alkali feldspars. II. A simple X-ray technique for the study of alkali feldspars"; O. F. Tuttle and N. L. Bowen, "The origin of granites in the light of experimental studies in the system $NaAlSi_3O_8$—$KAlSi_3O_8$—SiO_2—H_2O"; H. S. Yoder, "The role of water in metamorphism"; H. S. Yoder and H. P Eugster, "Synthetic and natural muscovites."

SUMMARY OF PUBLISHED WORK

(1222) The orthoclase-microcline inversion. W. S. MacKenzie. Mineralogical Mag., vol. 30, pp. 354-366 (1954).

The variable lattice of microcline is discussed, and two examples of the association of monoclinic and triclinic potash feldspar are described. The differences in the nature of the change from one form to the other in these two occurrences are considered important for establishing the relation between orthoclase and microcline.

(1223) A review of the Al–O and Si–O distances. J. V. Smith. Acta Crystallogr., vol. 7, pp. 479-481 (1954).

A review of the measured Al–O and Si–O distances leads to the values Al–O$=1.78\pm0.02$ Å and Si–O$=1.60\pm0.01$ Å. These values are of use in locating the positions of Al and Si atoms in feldspar or other structures by accurate measurements of distances in oxygen tetrahedra.

(1224) Discussion: Effect of change of origin on mean and variance of two-dimensional fabrics. F. Chayes. Amer. Jour. Sci., vol. 252, pp. 567-570 (1954).

The mean and variance of two-dimensional cyclical data are sensitive to the choice of origin. The strength of this effect and the mean from which the variance will be least can be determined prior to calculation of the variance.

(1225) The properties of glass. G. W. Morey. Amer. Chem. Soc. Monogr. Ser., No. 124. 2d ed., 591 pp. New York, Reinhold Pub. Corp. (1954).

This second edition contains much new material on complex experimental and commercial glasses, and new sections on the effect of heat treatment and of absorbed radiation on the properties of glass. The literature references are brought up to date.

(1226) Determination of the composition of natural nephelines by an X-ray method. J. V. Smith and Th. G. Sahama. Mineralogical Mag., vol. 30, pp. 439-449 (1954).

X-ray data obtained for 13 synthetic nephelines and 24 chemically analyzed natural nephelines show that the K/(K+Na+Ca) ratio can be determined for the natural minerals from X-ray powder diffraction patterns. The method does not permit a determination of the amount of silica present in excess over the ideal nepheline formula, but the error introduced by the excess silica into the determination of the K/(K+Na+Ca) ratio is very small.

(1227) The binary systems $NaPO_3$—KPO_3 and $K_4P_2O_7$—KPO_3. G. W. Morey. Jour. Amer. Chem. Soc., vol. 76, pp. 4724-4726 (1954).

The phase-equilibrium curves in the binary systems $NaPO_3$—KPO_3 and $K_4P_2O_7$—KPO_3 have been determined. In the system $NaPO_3$—KPO_3 a compound, $3NaPO_3 \cdot KPO_3$, is formed which melts incongruently at 552° to form crystalline $NaPO_3$ and a liquid containing 0.31 weight fraction KPO_3. $3NaPO_3 \cdot KPO_3$ is the stable crystalline phase from its incongruent melting point to its eutectic with KPO_3, at 547°, 0.505 weight fraction KPO_3. In the system $K_4P_2O_7$—KPO_3 a compound, $K_5P_3O_{10}$, is formed which melts incongruently at 641.5° to form crystalline $K_4P_2O_7$ and a liquid containing 0.54 weight fraction KPO_3. $K_5P_3O_{10}$ is the stable crystalline phase from its incongruent melting point to its eutectic with KPO_3, at 613°, 0.59 weight fraction KPO_3.

(1228) Phlogopite synthesis and stability range. H. S. Yoder and H. P. Eugster. Geochim. et Cosmochim. Acta, vol. 6, pp. 157-185 (1954).

A hydroxyl-bearing phlogopite has been synthesized and its upper stability limit determined up to 75,000 psi water vapor pressure. Above the upper stability limit the stable phases are forsterite+leucite+orthorhombic $KAlSiO_4$+vapor.

At the lowest temperatures investigated the mica grows quickly as randomly stacked, one-layer monoclinic phlogopite (1Md). At higher temperatures or with longer runs the mica orders to either a one-layer monoclinic (1M) or a three-layer trigonal (3T) polymorph. It is not possible to distinguish the 1M or the 3T polymorph by means of powder X-ray diffraction patterns; the two-layer monoclinic (2M) mica, however, is easily identified. The small size of the synthetic crystals prohibited identification of their poly-

morphic form by optical methods or single-crystal studies.

The upper stability range of two natural phlogopites is in accord with that of synthetic phlogopite. The transformation of a natural 2M to a 1M or a 3T was accomplished; the stability ranges of the natural phlogopite polymorphs could not be fixed, however, because of the sluggish nature of the transformations and the character of the recrystallization.

The occurrence of phlogopite in igneous rocks is accounted for by the relation of its stability curve to the minimum melting curves of "granite" and "basalt."

The trioctahedral clay micas are identified structurally as 1Md micas. The completely disordered phlogopite produced synthetically and its subsequent ordering well illustrate the observed stages of authigenic growth or, conversely, a weathering of the natural micas.

(1229) Silica and inorganic silicates. G. W. Morey. Encyclopedia of Chemical Technology, vol. 12, pp. 268–303 (1954).

The properties and structures of the forms of silica, and of about 150 of the commonest silicate minerals, classified according to the current concepts of their atomic structure, are given.

(1230) The system K_2O—MgO—Al_2O_3—SiO_2. I. Results of quenching experiments on four joins in the tetrahedron cordierite—forsterite—leucite—silica and on the join cordierite—mullite—potash feldspar. J. F. Schairer. Jour. Amer. Ceram. Soc., vol. 37, pp. 501–533 (1954).

A portion of the quaternary system K_2O—MgO—Al_2O_3—SiO_2 has been studied by the method of quenching, and results are presented on 193 separate compositions, which lie in a series of five triangular joins within the tetrahedron used to represent the quaternary system. These joins are leucite—forsterite—silica, forsterite—cordierite—leucite, cordierite—silica—leucite, magnesium metasilicate—cordierite—leucite, and cordierite—mullite—potash feldspar. One of these joins, leucite—forsterite—silica, is a ternary system within the quaternary system. The probable relations of protoenstatite, clinoenstatite, and enstatite (three crystalline forms of $MgSiO_3$) are discussed.

The data indicate within approximate limits the temperatures and compositions of eleven quaternary invariant points and describe the crystallization behavior of compositions in the volumes leucite—corundum—spinel—silica and leucite—forsterite—spinel—silica which occupy a large portion of the quaternary system. Some of the mixtures in these two volumes are rather close in composition to rock magmas. In these simplified magmas it is significant that the goal toward which crystallization proceeds during fractional crystallization is a granite, and that crystallization proceeds toward a granitic composition even if the magmas are contaminated by, and wholly or partially assimilate, basic igneous rocks such as peridotites or dunites, or highly aluminous sediments.

An examination of the stable assemblages of crystalline phases present at equilibrium in the portion of the quaternary system described shows that certain combinations of these phases are incompatible at and just below temperatures where a liquid phase is present, but might be changed at lower temperatures. These observations are of interest in metamorphic petrology.

It is always fortunate when results of pure research on geological problems can be of immediate use to industry. The data on crystallization and melting in the portion of the quaternary system just discussed predict the effects of the addition of K_2O, MgO, and SiO_2 on the refractoriness of high-alumina (mullite) refractories, and the effects of K_2O, MgO, Al_2O_3, and SiO_2 on basic (periclase or forsterite) refractories. The data provide information not only on the refractoriness, or lack thereof, of a large range of compositions, but also on the chemical, as distinct from the mechanical, aspects of the attack of slags on a wide range of refractories. They also furnish basic information which can be applied to many technical problems in the fields of ceramics and metallurgy.

(1231) Potash feldspar as a by-product of the biotite-chlorite transformation. F. Chayes. Jour. Geol., vol. 63, pp. 75–82 (1955).

Minute granules of potassium feldspar are disseminated through biotite, chloritized biotite, and chlorite in the Sierra de Guadarrama granite. They are rare in fresh biotite, but common in chloritized biotite and chlorite. Presumably they are one of the products of

the reaction by which biotite is transformed to chlorite; their erratic distribution through the rock suggests that this reaction is hydrothermal. With adequate staining technique, similar potassium feldspar granules can be found in almost any biotite granite; their preferential association with chlorite cannot ordinarily be established because of the minute amounts in which both minerals occur.

(1233) The ternary systems leucite—corundum—spinel and leucite—forsterite—spinel. J. F. Schairer. Jour. Amer. Ceram. Soc., vol. 38, pp. 153–158 (1955).

These ternary systems are limiting faces, respectively, of the volumes leucite—corundum—spinel—silica and leucite—forsterite—spinel—silica in the quaternary system K_2O—MgO—Al_2O_3—SiO_2. The results of quenching experiments on these two ternary systems and on the binary system spinel—leucite are given. The relation of the system leucite—corundum—spinel to the volume leucite—corundum—spinel—$K_2O \cdot Al_2O_3 \cdot 2SiO_2$ is indicated. The data presented are of general interest to the geologist and provide basic information which can be applied to refractories and slags by the ceramist and metallurgist. Some observations are made on the refractoriness and changes in refractoriness of certain mixtures of ceramic materials.

(1235) Annual report of the Director for 1953–1954.

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Sahama, Th. G. See Smith, J. V.

Schairer, J. F. The system K_2O—MgO—Al_2O_3—SiO_2. I. Results of quenching experiments on four joins in the tetrahedron cordierite—forsterite—leucite—silica and on the join cordierite—mullite—potash feldspar. Jour. Amer. Ceram. Soc., vol. 37, pp. 501–533 (1954).

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——— and Th. G. Sahama. Determination of the composition of natural nephelines by an X-ray method. Mineralogical Mag., vol. 30, pp. 439–449 (1954).

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DEPARTMENT OF PLANT BIOLOGY

Stanford, California

C. STACY FRENCH, *Director*

How is the light that is absorbed by chlorophyll in plants converted into chemical energy? This basic question of photosynthesis still remains unanswered.

The study of certain plant pigments other than chlorophyll, which absorb light and make it available for the photosynthetic process, gave promise of increasing our knowledge of the energy-storing process. But investigation of the photochemistry of these pigments made it evident that they act only by funneling their absorbed energy to chlorophyll *a* by resonance transfer. This leaves chlorophyll *a* as the ultimate pigment from which captured light energy is delivered to the chemical part of the photosynthesis machine. The enigma of the conversion of light energy to chemical energy by chlorophyll is still the basic problem.

It had long been surmised that chlorophyll participated chemically in photosynthesis in addition to absorbing the light. If so, a reversible chemical change ought to occur in chlorophyll which should alter its spectral absorption and hence that of the photosynthesizing organism. Many unsuccessful attempts have been made over a span of years to detect such an absorption change in living cells. This effect was discovered by Duysens a few years ago in purple bacteria. The photosynthetic pigment of purple bacteria is bacteriochlorophyll, whose principal absorption band lies in the near infrared. Duysens found the absorption in this band to be decreased by intense illumination and to recover rapidly in the dark.

In chlorophyll *a*-containing plants no such decrease of absorption in the chlorophyll absorption band has been observed. As discussed in last year's report, however, Duysens found an increased absorption by *Chlorella* cells in the green part of the spectrum when they were intensely illuminated. This result has been confirmed, with a technique entirely different from Duysens', by Witt in Germany.

There is some reason to believe that this increased absorption by *Chlorella* in the green part of the spectrum may be due to a chemical change in chlorophyll. The evidence for this possibility comes from experiments such as those of Livingston in Minnesota and Krasnovskii in Russia. These investigators found that absorption of solutions of extracted chlorophyll when illuminated under appropriate conditions increased in the green and decreased in the red, and that the change reversed in the dark. This photochemical change induced in chlorophyll has been postulated by Krasnovskii to be the first of the chemical reactions in the photosynthetic chain.

This reversible photochemical change has been observed only in chlorophyll dissolved in organic solvents; it has not been observed in chlorophyll in its natural state, i.e., combined with protein and possibly with fats and other pigments in what is now called the chlorophyll holochrome. Furthermore, the functional activity of chlorophyll—its participation in the splitting of water, the utilization of the hydrogen derived therefrom to reduce other substances, and the liberation of the leftover oxygen—is a property of the chlorophyll holochrome. The holochrome need not be in the intact leaf to perform part of its physiological function, because even in disintegrated chloroplasts the chlorophyll holochrome still possesses the ability to carry on the water-splitting step of photosynthesis.

It is hoped that ultimately the chlorophyll holochrome may be isolated from the morphological units in which it occurs (in chloroplasts or grana) so that these phe-

nomena may be studied with the separated pigment complex. But attempts at its isolation, which have been made by various persons, have been unsuccessful thus far. The difficulties encountered are undoubtedly due to the easy dissociation of the pigment from its carrier, the insolubility of the holochrome, and the large size of the ultimate units.

While efforts are being made toward the separation of the active holochrome, studies of absorption changes and induced chemical action are currently being carried forward with isolated chloroplasts, either whole or disintegrated, and with chlorophyll-containing fractions derived from these units by preparative methods of enzyme chemistry. The immediate objectives are to find out if the absorption changes observed in the green portion of the spectrum of extracted chlorophyll also take place in natural chlorophyll-bearing units and to determine whether these spectral changes are reversible; to make sure whether any spectral changes observed in these chlorophyll-bearing units are due to chlorophyll; and, if at all possible, to find out what chemical changes are brought about in the chlorophyll molecules.

If changes in absorption spectra, similar to those in extracted chlorophyll, are not observable in the chlorophyll of chloroplasts, to what can this difference be ascribed? Can it be due to enzymes which rapidly reverse the reaction so that changes are not detectable, or to a cycle which is coupled with changes in other chloroplast components so that the change at any time is too small to be found?

One of the interests of the Department during the past year has been the further development of a new way of measuring the absorption of light of different colors by the functional pigments in living plant material and in solutions of the extracted pigments. The principle of this method is to measure the increment in absorption for small intervals of wavelength. Some of its advantages, for certain purposes, over the conventional methods have been examined theoretically. The apparatus has been brought into shape for use in the investigation of the photochemistry of chlorophyll.

Another study which has many of the characteristics of the one already described is that on the transformation of protochlorophyll to chlorophyll *a*. Protochlorophyll when dissolved in organic solvents has never been photochemically converted to chlorophyll. Yet with protochlorophyll in its native state this photochemical reduction proceeds with great speed. This conversion takes place also in extracellular extracts of the holochrome in glycerine or in aqueous buffer solutions. Whether these extracts still contain the protochlorophyll holochrome in extremely small morphological units resembling mitochondria or microsomes is uncertain. But progress is being made in the isolation of the protochlorophyll holochrome in increasingly smaller units, and the hope is that by the methods of enzyme chemistry a true molecular dispersion of this complex substance may be obtained.

The isolation of this substance as a functional unit is greatly facilitated by the ease of its detection and by the simple transformation test for its activity. Isolation of the protochlorophyll holochrome and the establishment of its properties would greatly increase our understanding of the photochemistry of the active chlorophyll pigment complex of plants.

Experiments on the transformation of protochlorophyll to chlorophyll have been continued in water and in glycerine extracts of etiolated plants of various species. With barley, active extracts are obtained only in glycerine, not in water, and the chlorophyll formed has its peak absorption at 672 mμ. Bean leaves extracted by water give extracts which contain protochlorophyll capable of being transformed, and the resulting chlorophyll also has its absorption peak at 672 mμ, a value which seems to be generally characteristic of freshly formed chlorophyll rather than of the chlorophyll which accumulates in

thoroughly greened leaves. Squash cotyledons were found to give active extracts only in glycerine, and strangely enough the chlorophyll formed in such extracts has its absorption peak at 680 mμ, just as does that in mature leaves. When bean leaves and barley leaves are ground together in water, phototransformation of photochlorophyll in the extract of the bean leaves is partially inhibited by something from the barley.

All the extracts prepared so far show particles in a dark-field microscope. It is not known whether the protochlorophyll complex is necessarily associated with particles or whether it may be obtained in molecular solution. Experiments to answer this question are in progress.

The question whether the rate of protochlorophyll formation in leaves is rapid enough to account for the observed rates of accumulation of chlorophyll has been investigated by Dr. Virgin. He studied the rate of re-formation of protochlorophyll in leaves which had been illuminated and then returned to darkness. It was found that the rate of protochlorophyll re-formation was adequate to account for the rate of chlorophyll formation in illuminated plants for the first two hours of the experiment. There is some question still as to whether the greatly increased rate of chlorophyll formation after the first two hours of illumination can be accounted for by formation of chlorophyll through the protochlorophyll step, or whether some other reaction induced by this light period may supersede this process after a prolonged illumination.

Dr. Loeffler has been investigating the magnesium-containing precursors of protochlorophyll in etiolated barley seedlings and has found that the extra magnesium accumulated in illuminated plants is contained in an acidic fraction, which is being analyzed. One result of this work has been the discovery that from one-third to two-thirds of the total protochlorophyll in barley is of the phytol-free form. This substance has previously been found in a *Chlorella* mutant by Granick, but has not before been observed in higher plants.

During the year the range-grass program has proceeded with continually increasing interest from our various collaborators. Seed has been sent to the U. S. Agricultural Research Service for co-operative tests in fourteen different regions of the United States. The U. S. Soil Conservation Service has expanded the seed increase plots at both Pullman and Pleasanton, and plans preliminary tests in nine different areas in the far western states where the hybrid strains are likely to be of use. Samples of each strain and of the parental species have simultaneously been planted at the transplant stations of the Department. The testing program will make it possible to determine the ranges of tolerance of each strain and the regions where it would most likely succeed. It will also extend the transplant investigations into many climatically different regions besides the stations of the Department. The co-operative arrangement with Purdue University has been initiated through the joint appointment of a research assistant to make the crosses of selected grasses at Purdue and at the Department of Plant Biology and to carry through their development at Purdue. The University of Minnesota and the University of Texas are testing selected strains of the *Poa* hybrids and plan to carry out crossings of their own.

Experiments relating to the general program in experimental taxonomy occupy much of the garden space at Stanford and at the mountain stations. These experiments are designed to elucidate the complex genetic and environmental relations between and within wild species of plants. A new planting of the second generation of interracial crosses of yarrow whose parents came from coastal and alpine environments has now matured and is providing information about the hereditary constitution of the parental races. This experiment provides supplementary data for an investigation that has been in progress for some years.

By contrast with these long-term outdoor experiments, an investigation has been undertaken on the growth rates, under various laboratory conditions, of distinct species and strains of the miniature duckweeds. This work of Dr. Elias Landolt was started at the Department of Plant Biology and continued on a larger scale in the controlled environments of the Earhart Laboratory of Plant Physiology at the California Institute of Technology in Pasadena. The studies dealt with cultures of single, vegetatively multiplying individuals under aseptic conditions. The growth rates were measured with the addition of sugar as well as without sugar, the latter condition forcing the plants to manufacture their own food solely by photosynthesis. Strangely enough, there was little difference in the optimum temperature for growth between strains of the same species coming from climatically different regions. The differences were between species rather than between races of the same species. The species differences were expressed in growth rates, in optimal temperatures for growth, and in the temperature ranges within which growth was possible. Some species failed to grow at 32° C, whereas others grew well up to 38° C; some grew at temperatures as low at 4° C, whereas others died under these conditions or formed resting buds which sank to the bottom of the culture. The lack of distinct racial differences within the species is strikingly at variance with the findings in species of other plants grown in soil.

During the winter months of 1954–1955 the experimental taxonomy staff devoted considerable time to preparing a manuscript for the fourth volume of *Experimental Studies on the Nature of Species.* This work is concerned with comprehensive experiments on the ecological genetics of climatic races of *Potentilla glandulosa,* a distant relative of the strawberry. A significant feature of these experiments is that the analysis of the heredity was carried out in three environments on divided plants of second-generation interracial hybrids. This has never been done before, and it has led to a new and comprehensive picture of the way in which the heritable factors that control the development of characters in natural races express themselves in three contrasting environments after they have been shuffled through hybridization. The systems of genes are so constituted that they tend to maintain the identity of the race, and yet the systems have the capacity for producing almost infinite numbers of new forms, a capacity that is significant when the environment changes. There are very few previous data in this field, and no work of anywhere near this magnitude, in spite of the importance of such experiments in the study of plant evolution. Such data also may be of value to practical plant breeding, as they show the inheritance patterns of crosses from widely divergent types of a single species. The original crosses for this experiment were made in 1932, and many plants of the second generation were put in at the transplant stations in 1938. Extensive data were collected through 1947, and the plants at the mountain stations are still under observation.

PERSONNEL

Biochemical Investigations

Staff: C. Stacy French, *Director,* Harold W. Milner, James H. C. Smith

Research Fellows: Robert W. Krauss, Josef E. Loeffler, Hemming I. Virgin

Research Assistants: Allen Benitez, Arthur T. Giese, Victoria H. Lynch

Technical Assistants: Ingrid M. Ahrne, Allen B. Church, Frederick Kurzweil, Jr.

Stanford University graduate student associated with the Department: Richard W. Eppley

Experimental Taxonomy

Staff: Jens C. Clausen, William M. Hiesey

Visiting Investigator: Elias Landolt

Research Assistants: Malcolm A. Nobs, Paul L. Pfahler, Thomas R. Pray

Technical Assistants: Lois M. Cox, John F. Hansen, Edward L. Triplett
Clerical Assistant: Alberta B. Caswell
Gardener: Wesley B. Justice

Research Associate

Ralph W. Chaney, Professor of Paleontology, University of California, Berkeley

Department Secretary

Wilbur A. Pestell

Mechanical Engineer

Louis R. Kruger

Custodians

Frank E. Russell, Webster L. Smalley

Dr. Jens C. Clausen was elected a foreign member of the Royal Swedish Academy of Sciences and served during the year as vice-president of the Society for the Study of Evolution. He attended the International Arid Lands Conference at Albuquerque, New Mexico.

Dr. James H. C. Smith has served as a director of the newly formed Santa Clara Valley Section of the American Chemical Society.

Dr. C. Stacy French served as chairman of the Western Section of the American Society of Plant Physiologists and as vice-president of the Society of General Physiologists.

During the year Dr. Elias Landolt spent about four months at California Institute of Technology studying the effect of various controlled environments on the growth of duckweeds.

Dr. Harlan Lewis, associate professor of botany at the University of California, Los Angeles, has been using the Department's facilities at Mather while on a Guggenheim fellowship.

During the summer season of 1954 Dr. Th. Dobzhansky, of Columbia University, continued his investigations at the Mather and Timberline stations in a cooperative study of climatic races of *Drosophila,* with the aid of the same group of collaborators mentioned in the report for 1953–1954 (Year Book No. 53).

BIOCHEMICAL INVESTIGATIONS

The Holochromes of Etiolated Tissues

James H. C. Smith and Ingrid M. Ahrne

In order to analyze further the system in etiolated leaves which converts protochlorophyll to chlorophyll, the system has been removed from the living leaf by grinding the leaf either in glycerine or in dilute buffer solution. The extracts after being strained, centrifuged, and homogenized by means of the French-Milner homogenizer are cell-free. They have the characteristic absorption spectrum of the protochlorophyll holochrome, and when illuminated they acquire the characteristic absorption spectrum of the chlorophyll *a* holochrome. This year some progress has been made toward determining the nature of the system undergoing this phototransformation.

Tissues from various plants differ in ability to yield extracts of the protochlorophyll holochromes that are suitable for investigation. Dark-grown bean and barley leaves and the cotyledons of Hubbard squash yield extracts in glycerine which give well-defined absorption spectra of the protochlorophyll holochrome and maintain their ability to effect the photoconversion of protochlorophyll. But of these three, only bean leaves yield an extract in aqueous buffer solution which has these properties. The buffer extracts of dark-grown barley leaves and squash cotyledons contain little or no protochlorophyll holochrome, and on being illuminated show no evidence of the production of chlorophyll holochrome. In fact, the buffer extract of barley leaves seems to contain an inhibitor for the transformation, because when it is mixed with the buffer extract of bean leaves it depresses the transformation in the latter. The partial inhibition of this transformation has not been further examined.

The absorption maxima of the proto-

chlorophyll and chlorophyll holochromes have varying positions. In Year Book No. 52, 1952–1953 (p. 152), examples of this variability were reported. For instance, some extracts of protochlorophyll holochrome in cold glycerine from dark-grown barley leaves showed an absorption maximum as far to the red as 650 mμ, and some after they had stood in the dark at room temperature for two hours showed a shift in absorption maximum as far toward the blue as 635 mμ. Usually the absorption maximum of the initially extracted holochrome was at about 640 to 645 mμ. Also, the chlorophyll *a* holochrome formed by phototransformation of the extracted protochlorophyll holochrome had its absorption maximum at 672.5 mμ, whereas the chlorophyll *a* holochrome extracted from a fully green leaf had its absorption maximum near 678 mμ.

During the year under review, observations on the wavelength positions of the holochromes have been repeated and extended. The protochlorophyll holochrome from etiolated bean leaves has an absorption maximum at about 640 mμ in glycerine extract, but at about 632.5 mμ in dilute aqueous buffer extracts. The chlorophyll *a* holochrome produced by illuminating the protochlorophyll holochrome extracts in glycerine has an absorption maximum at about 675 mμ, and in buffer at about 672 mμ. In glycerine extracts of etiolated squash cotyledons the absorption maximum of the protochlorophyll holochrome lies at about 645 mμ, and that of the chlorophyll *a* holochrome formed therefrom by illumination has its maximum at 680 mμ.

The absorption bands of the extracted protochlorophyll and chlorophyll *a* holochromes from bean leaves and squash cotyledons are much more pronounced than those from barley leaves. For this reason the absorption maxima of the holochromes from bean leaves and squash cotyledons are much more easily determined than those from barley leaves. In fact, the absorption band of the barley-leaf protochlorophyll holochrome sometimes shows no definite maximum, but appears only as a shoulder on the experimentally determined absorption curve.

All these extracts scatter light. Since the experimentally measured absorption is the sum of the absorption by the pigment and the loss of light due to scattering, the measured absorption often gives a very distorted picture of the true absorption by the pigment. In order to obtain the true absorption, means have been sought to eliminate the effect of scattering. The most satisfactory method found thus far is that of Treiber and Schauenstein. In this method the optical density of the extract is measured in two contiguous regions of the spectrum, one in which the measured optical density is caused only by the loss of light due to scattering, and the other in which it is caused by both scattering and true absorption of the pigment. In the region where only scattering causes the absorbance, the following mathematical relation holds:

$$\log A - \log A_0 = K(\log 1/\lambda - \log 1/\lambda_0)$$

In this equation A_0 is the absorbance and λ_0 the wavelength from which the reckoning starts; A is the absorbance at any other wavelength, λ, in this region; and K is a constant determined by substitution of the experimental data in the equation. From the equation the correction for scattering can be calculated throughout the region of absorption by the pigment. When the correction is subtracted from the observed values, the pigment's true absorbance can be found.

In table 1 are listed the positions of the absorption maxima of protochlorophyll holochromes extracted from various etiolated tissues and of the chlorophyll holochromes produced therefrom by illumination, as determined from the absorption curves corrected for scattering. Mr. A. T. Giese determined the correction due to scattering with the curve analyzer described by French *et al.* in Year Book No. 52 (p. 162).

It is noteworthy that the position of the absorption maximum of the chlorophyll *a* holochrome of squash cotyledons lies at as long a wave length as does that of the chlorophyll *a* holochrome extracted from fully greened leaves. There is indication that the holochrome from the cotyledons is much richer in fat than the holochromes examined from other etiolated tissues. This suggests that the difference in position of the absorption maxima of chlorophyll *a* holochrome from briefly illuminated etiolated leaves and from fully greened leaves is due to a higher fat content in the latter.

The varied positions of the absorption maxima of the holochromes from different tissues leave little doubt but that the association of pigment with carrier differs in these tissues. What the differences are, and what physiological significance they may have, still remain to be determined.

TABLE 1

Wavelengths (in mμ) of absorption maxima of holochromes

Material	Protochlorophyll	Chlorophyll *a*
Bean leaves:		
Glycerine extract	642	675
Buffer extract	635	673
Barley leaves:		
Glycerine extract	645	672.5
Squash cotyledons:		
Glycerine extract	648	681

Whether the holochrome as extracted in glycerine and in buffer solutions exists in a molecularly dispersed state or is contained in small organized particles such as proplastids, grana, or mitochondria is still a question. An answer to this question has been sought by the use of various physical methods—centrifugation, dark-field microscopy, and filtration. These experiments are in a preliminary stage and the conclusions reached are only tentative, but it appears at present that the holochrome is contained in particles resembling grana.

The evidence on which this conclusion is based is here outlined. The pigment still remained in suspension in buffer solution after being centrifuged for one hour at 50,000 × g. (For carrying out the centrifugation we are indebted to Dr. Donald Kupke, of the Chemistry Department, Stanford University.) The supernatant from this centrifugation still contained particles about 2 to 5 μ in diameter which were visible with dark-field illumination. When this supernatant was passed through a Millipore Filter rated by the manufacturer to retain particles larger than 0.43 μ, both the specific spectral absorption and the microscopically visible particles were largely removed. Although this result would point to the pigment's being in particles, further tests need to be applied to prove this. Work on the problem is being continued.

Precursors of Protochlorophyll in Etiolated Barley Seedlings

Josef E. Loeffler

Considerable progress has been made in understanding the biosynthetic chain leading to the formation of chlorophyll since it was demonstrated a few years ago in this laboratory that protochlorophyll is the immediate precursor of chlorophyll *a*. It has been found in other laboratories that acetate and glycine are the primary compounds from which chlorophyll is derived, and, by use of "genetic blocks" in *Chlorella,* Granick has demonstrated the synthesis of a few relatively complex substances which may be precursors of chlorophyll. He has arranged these substances in the order of their complexity to give a rational scheme for the path of chlorophyll biosynthesis. None of these precursors, except protochlorophyll, has been isolated from higher plants.

In order to establish the path of chlorophyll biosynthesis, it will be necessary to isolate the different precursors from normal plants and to demonstrate their stepwise conversion into the next higher members of the sequence. In 1949, Smith

showed that precursors other than protochlorophyll were formed in higher plants by demonstrating that ether-soluble magnesium compounds increased in etiolated plants when they were illuminated at 0° C. During the past year the search for the magnesium-containing precursors to protochlorophyll has been extended.

The experiments showed that illumination of etiolated barley seedlings, followed by a dark period, resulted in an increase of magnesium bound in organic compounds. These compounds were fractionated by distribution between immiscible solvents and found to consist of two principal fractions: the newly formed chlorophyll, and another fraction that had the absorption spectrum of protochlorophyll. The latter fraction, although spectroscopically homogeneous, was a mixture of two components—one neutral, the other acidic.

The neutral component was protochlorophyll, as evidenced by its absorption spectrum, hydrochloric acid number, and Rf values as determined by paper chromatography. The acidic component had an absorption spectrum typical of protochlorophyll, but its solubility properties, hydrochloric acid number, and Rf values differed from those of protochlorophyll. The acidic component and protochlorophyll had hydrochloric acid numbers of 11 and 22 respectively, and Rf values of 0.26 and 0.80 when the paper chromatograms were developed with a mixture of petroleum ether, ether, and ethanol. The acidic component contained magnesium. When treated with acid it produced a magnesium-free compound whose absorption spectrum was identical with that of protopheophytin. From the various properties of this substance, it was concluded that the acidic compound was magnesium vinylpheoporphyrin a_5, i.e., protochlorophyll in which the propionic acid group is not esterified with phytol.

The ratio of this compound to protochlorophyll in seedlings seems to vary with the age of the seedling, but further work is necessary to verify this observation. The presence of this compound in normal plants makes it reasonable to assume that it is the immediate precursor to protochlorophyll. This suggestion is in line with the scheme for chlorophyll biosynthesis proposed by Granick from his experience with *Chlorella* mutants.

Several techniques had to be modified or developed for the separation, detection, and estimation of these organic magnesium-containing compounds. A simple micro method for the colorimetric determination of magnesium, using Tropaelin 00, was developed for following the fractionation of the compounds. This method was capable of estimating from 0.05 to 10 μg of magnesium. Under optimal conditions it was accurate to about 5 per cent.

The various pigments—pheophytins, magnesium vinylpheoporphyrin a_5, protochlorophyll, and chlorophylls—could be readily separated by ascending paper chromatography. The solvent used was a mixture of petroleum ether, ether, and ethanol in the proportion 30:10:0.5. The pigments could be identified by their positions in the chromatogram and by their characteristic absorption spectra, obtained without eluting the pigment from the paper by applying Shibata's method for absorption spectroscopy of turbid solutions. Which of the adsorbed compounds contained magnesium could be determined by developing the chromatogram, turned through a 90-degree angle, with an ether-ethanol solution of 1,5-diphenyl carbohydrazide. As this reagent ascended it decomposed the magnesium-containing organic compounds and formed red spots where the magnesium compounds had been. It also carried the organic residues, along with other adsorbed organic substances, in the solvent front and out of the chromatogram. This procedure provides a relatively fast method for determining the influence of different factors, such as age of seedlings, extent of illumination and dark periods, and temperature, on the formation of various organic magnesium compounds involved in the formation of chlorophyll.

Chlorophyll Formation and Greening

Hemming I. Virgin

It has long been known that plants grown in darkness accumulate small quantities of protochlorophyll. For some unknown reason, this accumulation stops when the pigment reaches a certain concentration. When the leaves containing this pigment are illuminated for a short time, they transform it to chlorophyll *a*. On being returned to the dark, the briefly illuminated leaves again build up protochlorophyll to about the level contained by them before their exposure to light. Subsequent irradiation of the leaves transforms this newly made protochlorophyll to chlorophyll. But dark-grown leaves that are continuously illuminated soon accumulate chlorophyll in far larger amount than can be accounted for by the amount of protochlorophyll they possessed before this illumination. As a result of these various observations it has been assumed that all the chlorophyll accumulated by green leaves has been derived from protochlorophyll and that protochlorophyll is continually being produced during illumination of the leaves. Evidence substantiating this assumption could be obtained by showing that the rate of protochlorophyll production is great enough to account for the rate of accumulation of chlorophyll. To obtain this evidence, dark-grown barley leaves were illuminated in order to convert their accumulated protochlorophyll to chlorophyll. After the leaves were returned to the dark, the rate of formation of protochlorophyll was measured and compared with the rate of accumulation of chlorophyll. These experiments were carried out at a series of temperatures.

The measurements were made by means of the fluorescence spectrophotometer. This instrument was sensitive enough to measure the relative concentration of chlorophyll and protochlorophyll in a piece of leaf weighing only 5.5 mg. Owing, however, to irregularities in the distribution of pigment in leaves, it was found better to make the pigment determinations on acetone extracts of the ground-up tissue.

The rate of accumulation of protochlorophyll in barley leaves kept in darkness increased rapidly at first and gradually slowed as the limiting concentration of pigment was approached. This limiting concentration was reached after about eight hours. The rate of formation of protochlorophyll about doubled for a 10-degree temperature increase in the range between 0° and 15° C, i.e., the Q_{10} was about 2. Within the temperature range 15° to 30° C the Q_{10} was only slightly above 1. Also, the final protochlorophyll concentration about doubled for a 10-degree rise at temperatures between 0° and 15° C, whereas it changed very little between 15° and 30° C.

The measurements at different temperatures demonstrated that the initial rates of formation of protochlorophyll were rapid enough to account for rates of chlorophyll formation during the first one or two hours of illumination. This was true for all light intensities used. After one or two hours of continuous illumination, however, the course of chlorophyll formation varied with the light intensity. At low intensity (0.36 foot-candle), chlorophyll formation continued at a constant rate. But at higher intensities the rate suddenly increased, and, regardless of the intensity, provided it was above a certain threshold, the sudden increase appeared after about the same period of illumination. For technical reasons, it was impossible to determine whether or not the rate of formation of protochlorophyll was proportionately increased at this point, but the rate of chlorophyll formation was much more rapid than corresponded to the rate at which protochlorophyll had formed in the earlier stages of greening.

These results suggest either that light somehow influences the rate of protochlorophyll formation or that chlorophyll in the later stages of its formation is derived from another precursor besides protochlorophyll.

The first traces of chlorophyll *b* could be detected after about one hour of il-

lumination. After this, the rates of formation of chlorophylls *a* and *b* bore a constant ratio to each other. Consequently, after a period of illumination chlorophyll *b* showed an increased rate of formation corresponding to that of chlorophyll *a*.

Derivative Spectrophotometry: Apparatus

C. S. French and Allen B. Church

The possibility of using the first derivative of the transmission spectra for studying the pigments contained in living cells was discussed in last year's report. During this past year the instrument developed for measuring such spectra, the derivative spectrophotometer, has been considerably improved and has been put into use for measuring changes in chlorophyll absorption spectra caused by illumination under certain conditions. Figure 1 illustrates the principles on which the apparatus operates. In order to obtain the derivative spectrum for a sample, it is still necessary to record four curves and from them to calculate the desired result. The necessity for measuring these four curves is not too serious a limitation, but means that the light source and the sample have to be constant for each pair of records.

The required curves are, first, the pair needed for determining the transmission of the sample, like those of figure 2. These are made with the monochromator slits set for a half band width of 1 mμ and with a vibrating slit in the sample beam adjusted to alternately transmit the light and cut it off entirely. One curve, with the solvent but without the sample, represents 100 per cent transmission. It should be flat and of constant height. Actually it deviates enough from this ideal so that it must be recorded. The other curve of the first pair is measured similarly but with the sample in place. The ratio of these two curves gives the sample transmission spectrum.

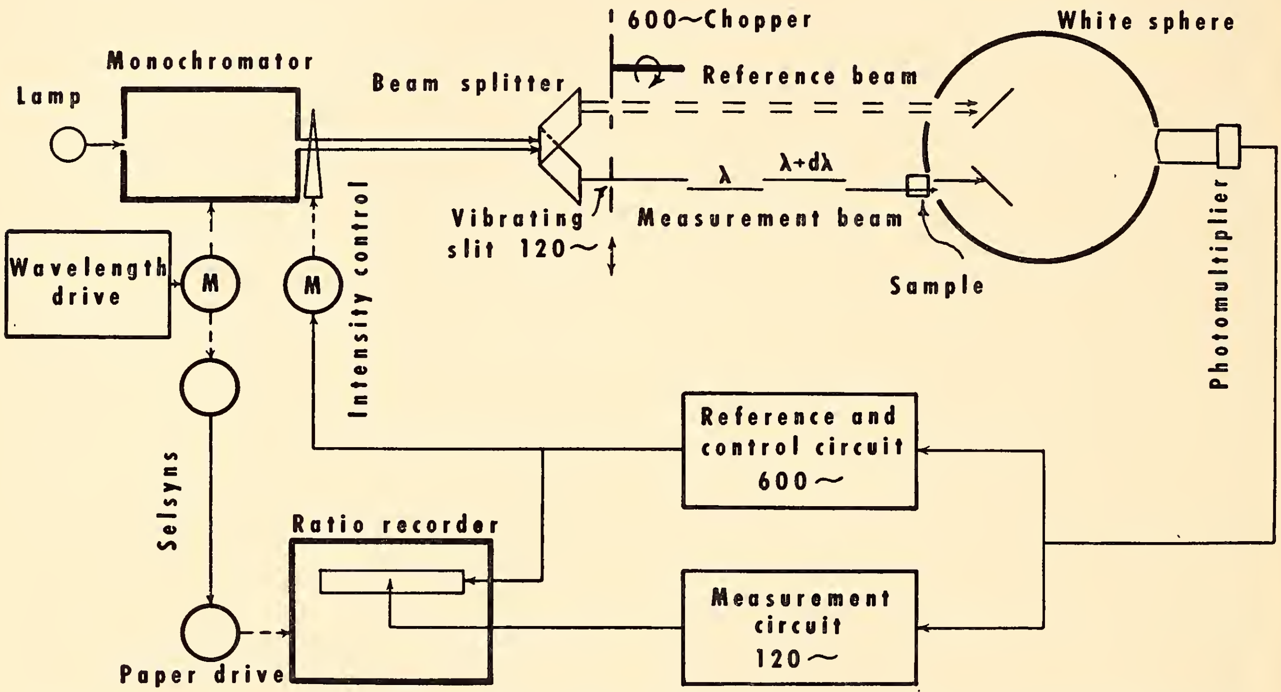

Fig. 1. Block diagram illustrating the operating principles of the derivative spectrophotometer

The second pair of curves for derivative determinations are recorded with a wide monochromator exit slit and with the vibrating slit set to alternate between two wavelengths a few millimicrons apart in the spectrum. For this derivative measurement, illustrated in figure 3, one curve has to be made without the sample and one with it in place. The first derivative of transmission with respect to wavelength

(fig. 4) is calculated at each wavelength from the relation $dT/d\lambda = K(R_s - TR_i)$, where R_i is the response of the instrument without sample, R_s is the response with the sample in place, and T is the transmission of the sample. The derivative of optical density, with respect to wave length, may be obtained from the same data by the relation $dE/d\lambda = K(R_i - R_s/T)$. K may be evaluated if necessary from similar measurements of a known standard glass filter.

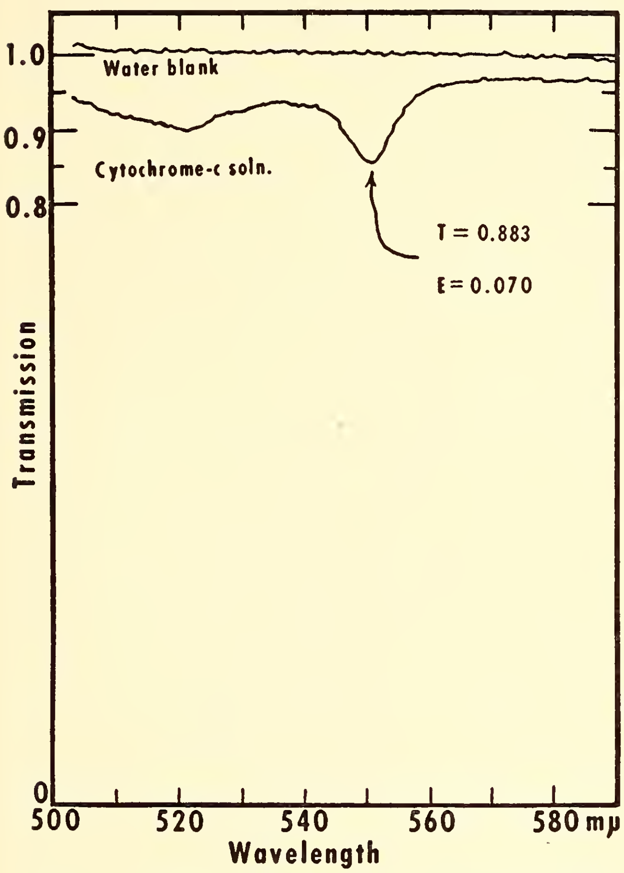

Fig. 2. Light transmission, at various wavelengths, of a dilute solution of reduced cytochrome c. This same solution was used for the measurements of figures 3 and 4.

The over-all response curve of the instrument has a peak in the middle of the usable range, which is from 400 to 750 mμ. For measurements of the transmission of the sample, the response curve can be corrected by recording the ratio of the responses to two beams, one going through the sample and the other entering the light-measuring sphere directly. In order to calculate the derivative spectrum of the sample, the slope of the response curve as well as its height must be considered at each wavelength, and also the transmission of the sample. The height of the response curve, its slope, or the sample transmission can be automatically compensated by servo-driven light-weakening devices or by ratio recording. We have not been able to devise a system to compensate for these three variables together that would be free of interaction between the controlled quantities.

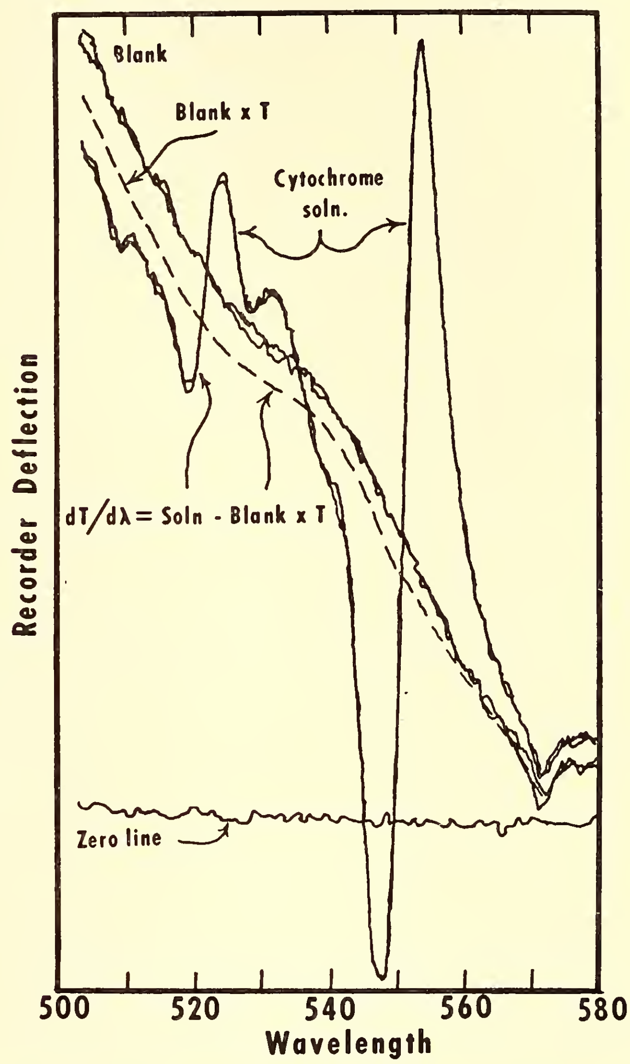

Fig. 3. Derivative records used in calculating the curve of figure 4

This year the optical parts have been mounted solidly but adjustably on a cast-iron base and covered with a light-tight metal box. Arrangements have been made for illuminating the sample from the side while its transmission or the derivative of

transmission is being measured. Complementary filters are placed in this side beam and in front of the photomultiplier tube. A lens system has been added to project the slit images to a greater distance from the vibrating slit, and this arrangement has greatly increased the space available for putting in samples.

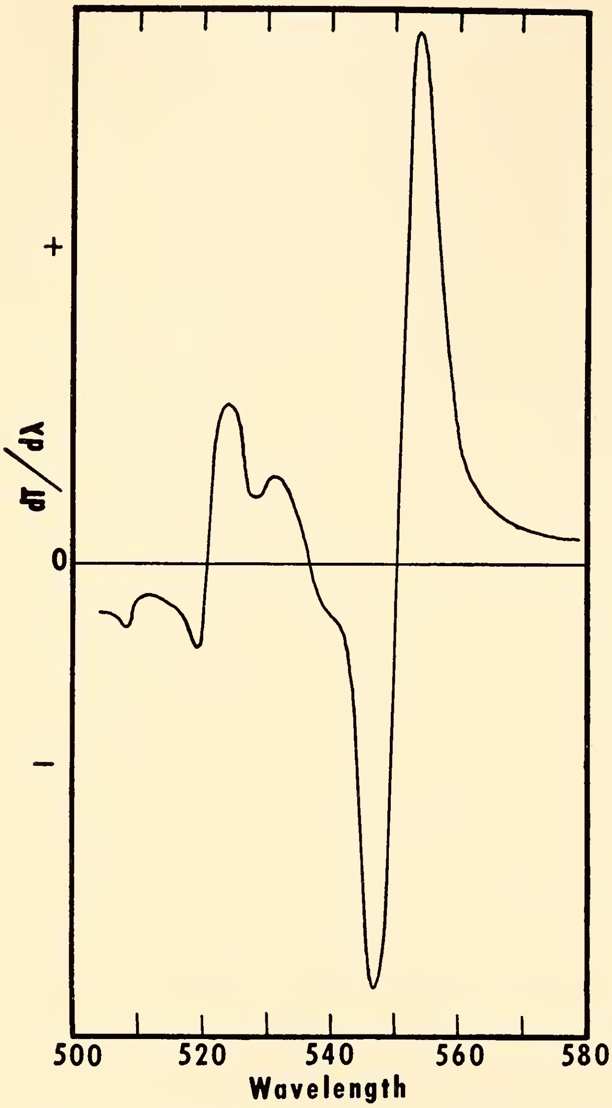

FIG. 4. First derivative of transmission with respect to wavelength of a dilute solution of cytochrome c. This curve shows considerably more detail than does the transmission spectrum, particularly in the region of the 520-mμ peak. This was a commercial sample of cytochrome c, and it is not yet sure that all the components indicated in this figure are attributable to pure cytochrome c.

The vibrating bar and fixed slit previously used have been replaced by an adjustable vibrating slit which gives much less trouble. For derivative measurements, any desired distance of slit vibration in the spectral plane up to 7.8 mμ may be used. The vibrating slit is set to pass a spectral band of 1 mμ half width. An improved 120-cycle amplifier has been put in, a preamplifier has been added to the photomultiplier tube housing, and various improvements have been made in the electronic system.

One of the major nuisances in derivative measurements has been the introduction of extraneous peaks from the so-called neutral wedge used to compensate for the height of the over-all response curve by means of a servo system. Better performance is being obtained by relying only on ratio recording, although the spectral range usable this way without readjustment is of course limited.

A solution of reduced cytochrome c has been used for testing the performance of

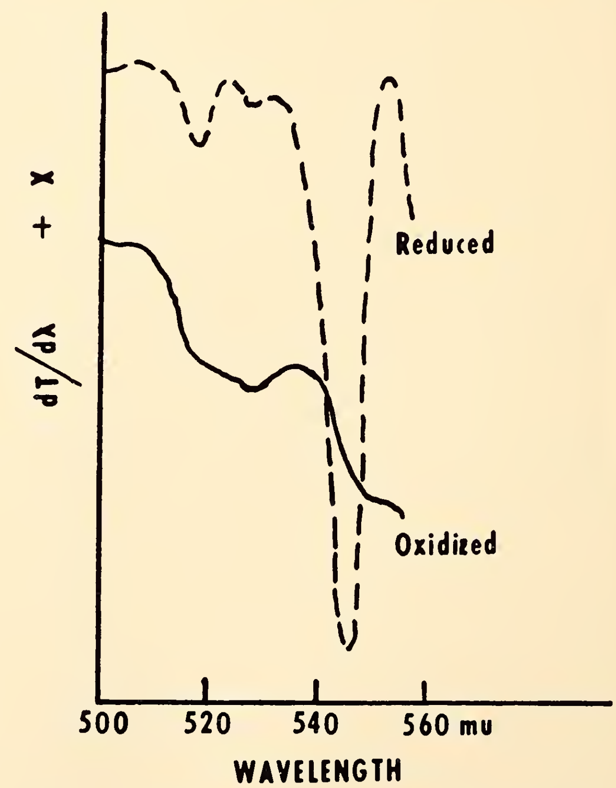

FIG. 5. Uncorrected derivative spectra for an oxidized and a reduced suspension of yeast. The transmission of this suspension was approximately 4 per cent. The similarity between this and figure 4 shows that the reduction of cytochrome c in living cells may be measured by this type of spectrophotometry.

the instrument. A dilute solution absorbing only 12 per cent at the height of the 550-mμ peak gave a satisfactory derivative spectrum which showed more structural details than can be found in the transmission spectrum itself. A yeast suspension transmitting about 4 per cent of the incident light gave derivative spectra (fig. 5) that showed very clearly the difference between oxidized and reduced cytochrome. Though it is to be hoped that several improvements can be made in the future, the apparatus is now in use.

Derivative Spectrophotometry: Reference Curves

Arthur T. Giese and C. S. French

Derivatives of absorption spectra have a more complicated shape than the usual plots of optical density against wavelength. That we might become familiar with the appearance of derivative spectra, some hypothetical absorption bands of typical shape were converted to transmission derivative curves by computation. Absorption bands, both single and composed of two overlapping components of various heights and wavelength separations, were used. The individual bands were probability curves, $E=ae^{-bx^2}$. They were combined and a large number of corresponding transmission derivatives plotted with the curve analyzer. Several interesting properties of derivative spectra became apparent in the study of these hypothetical spectra.

This collection of reference curves was prepared as a guide to the understanding of measured transmission derivative curves, and is also helpful in deciding on a suitable thickness or concentration of the sample to be measured.

A single absorption band, as can be seen, has a symmetrical derivative which is negative on one side of the peak, zero at the peak wavelength, and positive on the other side. The addition of a minor band on the side of a larger one may be undetectable by eye on the absorption plot and yet give a derivative curve which is clearly unsymmetrical. Figure 6 illustrates the greater sensitivity of derivative curves for this purpose.

A particularly striking example of the utility of derivative measurements is shown when two absorption bands of different widths but with their absorption maxima at the same wavelength are superposed. As shown in figure 7, these two bands

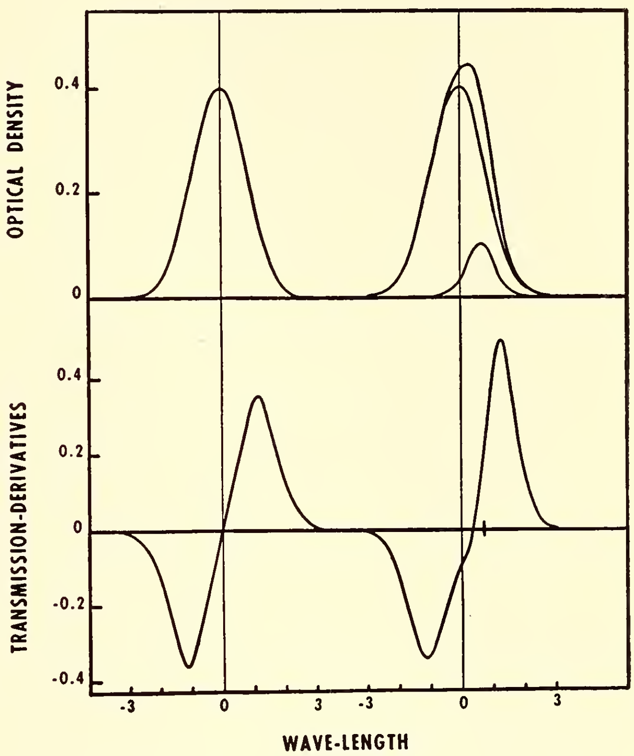

Fig. 6. The upper left curve represents a hypothetical absorption band having the shape of a normal probability curve. Below it is the first derivative of the corresponding transmission curve. The set of curves on the right includes the same hypothetical absorption curve and a smaller curve which has one-quarter the height and one-half the width of the other and is shifted in position. The appearance of the top curve, which is the sum of these two, only very vaguely suggests the presence of two components. The transmission derivative, however, shows a strongly marked lack of symmetry.

when added together give an extinction or transmission curve which is slightly sharpened at the peak but whose appearance would not lead one to suspect that it was made up of two components. The transmission derivative curve, however, shows two peaks on each side, the sharp one being

due to the narrow band. The symmetry of the derivative curve shows that both bands have the same wavelength. It thus turns

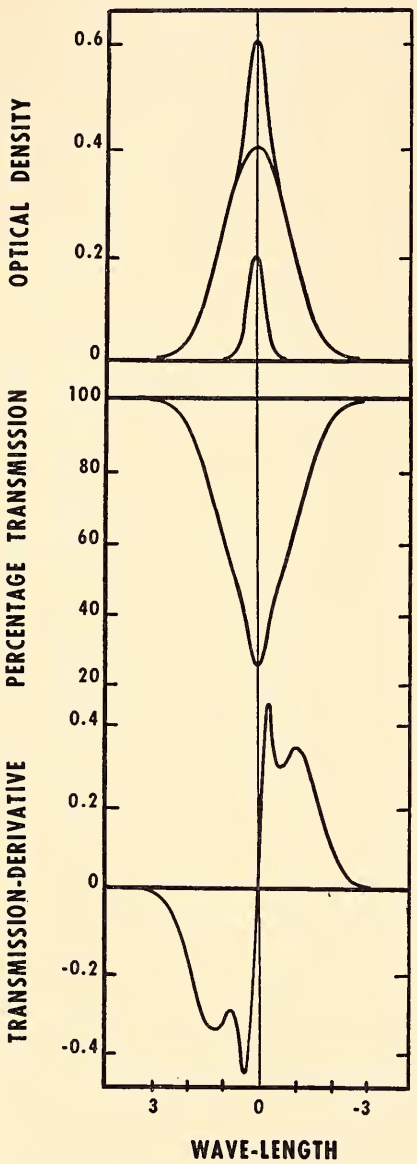

Fig. 7. The upper part shows two hypothetical absorption bands having their peak positions at the same wavelength. The smaller one is one-half the height and one-quarter the width of the larger. The sum of these two curves is also shown. The percentage transmission corresponding to the top curve is shown in the middle figure. At the bottom is given the first derivative of the transmission curve with respect to wavelength. The presence of two superimposed bands would hardly be suspected from visual observation of the optical density or of the transmission curves. The derivative, however, shows very strikingly two sharp peaks.

out that derivative spectroscopy can resolve two bands of identical wavelength provided they differ enough in width.

All these derivative curves were computed as derivatives of transmission, T, rather than as derivatives of extinction coefficient, E. Transmission curves and their derivatives have different shapes for samples of different thickness or concentration. Extinction or optical-density curves vary only in scale and not in shape as the thickness of the sample is increased, and are therefore usually used rather than transmission curves in absorption spectrophotometry. The relation between these two quantities is $E = \log(1/T)$. Many recording spectrophotometers use a logarithmic slide-wire so that E rather than T may be plotted automatically. We do not have a logarithmic slide-wire in the derivative spectrophotometer. Nevertheless it is just as easy to compute $dE/d\lambda$ from our recorded data as to obtain $dT/d\lambda$. This follows from the differentiation of $E = \log(1/T)$, whereby $dE = -dT/T$. T must be measured anyway to get $dT/d\lambda$, because of the way in which the derivative spectrophotometer operates. It seems likely that in the future, plots of $dE/d\lambda$ will be used in preference to $dT/d\lambda$ to avoid the change of shape with variations in sample thickness.

Changes in Chlorophyll Absorption Spectra Caused by Light

Victoria H. Lynch and C. S. French

It has been found in other laboratories that pure chlorophyll in organic solvents free of oxygen changes its absorption spectrum greatly when illuminated, and in the dark rapidly reverts to its original state. Chlorophyll in pyridine with reducing substances such as ascorbic acid is known to undergo a somewhat similar change. In this system the reversion takes place much more slowly. This effect has been interpreted as a reduction of chlorophyll and has been postulated as the primary photochemical step in photosynthesis.

We have confirmed some of these observations and are attempting to see if analogous effects can be detected in chlorophyll which has not been removed from

the state of combination as a protein complex in which it exists in nature.

We have followed the changes produced by light in a chlorophyll–pyridine–ascorbic acid system. Both white light and red light were found to be effective in causing the disappearance of the chlorophyll absorption bands and the appearance of a new peak with an absorption maximum at 525 mμ. The rate of disappearance of the red chlorophyll peak (672 mμ) and the rate of appearance of the green peak (525 mμ) of the changed chlorophyll were found to be the same. The regenerated chlorophyll transmission curve was identical with the original transmission curve.

We have found that illuminated chloroplasts suspended in 0.5 M sucrose with ascorbic acid show no measurable changes. Addition of small amounts of pyridine produces no detectable effect. If the pyridine concentration is raised to about 50 per cent, the chloroplasts are broken and the chlorophyll is dissolved out from its natural complex holochrome, as is indicated by the increased fluorescence. The spectral changes discovered by others can then be observed. These spectral changes of chlorophyll have been measured using the transmission spectra and the derivative spectra.

Because of the chance that this photochemical effect of chlorophyll may be a part of the mechanism of photosynthesis, further work is planned in the attempt to correlate the known photochemistry of pure chlorophyll with the spectral changes caused by light in living cells.

A Special Effect of Light on the Growth of Chlorella vulgaris [1]

Allen Killam and Jack Myers

In analysis of the light requirement for growth of algae it has been common practice to assume that light controls only the photosynthetic reduction of carbon dioxide to products such as carbohydrate. It has been known since the time of Beyerinck that *Chlorella* and other algae can be grown in darkness when glucose is provided as an organic substrate, although at a rate usually lower than that supported by photosynthesis under light and carbon dioxide saturation. Occasional evidence has been presented that light stimulates the rate of growth on glucose through a direct effect on glucose utilization; unfortunately all such evidence has been inconclusive, since experimental design has not precluded the possibility of an added photosynthesis of the carbon dioxide produced oxidatively. More convincing evidence for the stimulatory effect of light has been provided by the observation of Finkle, Appleman, and Fleischer (1950) that a strain of *Chlorella* would not grow without light from small inocula on a glucose medium. This observation has been followed up by the technique of searching for effects of very small amounts of added light. The basic premise is that any special effects of light (beyond contribution to bulk photosynthesis) should be produced by very low light intensities.

Growth rates of different algae were observed in test-tube cultures by periodic readings in an Evelyn colorimeter with 600-mμ filter. The cultures were grown in a Knop's solution, aerated continuously with 4 per cent carbon dioxide in air, and with or without added glucose. Cultures were maintained in darkness or under a light intensity so low that it would just barely support growth by photosynthesis alone. With *Scenedesmus obliquus* (D3) and *Chlorella pyrenoidosa* (Emerson strain), the specific growth rates observed with the limited light plus glucose are only slightly greater than the sum of the growth rates on glucose in darkness and with limited light alone. The *Chlorella vulgaris* (Emerson strain) used by Finkle *et al.* behaves quite differently, however, as is evidenced by the following typical specific growth rates expressed in $\log_{10}$ units per day: glucose in darkness, 0.10; limited light only, 0.01; limited light plus

[1] This work is being done at the University of Texas.

glucose, 0.39. Here the effect of the limited light is more than additive, and an effect of light other than its contribution to bulk photosynthesis is demonstrated.

Further work was devoted to the special stimulatory effect of light on the growth of *Chlorella vulgaris.* In the experiments described above, cultures, even though grown in darkness, receive a very small amount of illumination in the process of taking colorimetric density readings. In further work, rigorous precautions were taken to exclude access of light, and growth was determined by initial and final cell counts. Zero growth on glucose in the dark was observed only in cultures started from very small inocula (<100 cells per ml) taken from agar slants. Cultures started from either small or large (ca. 10^5 cells per ml) inocula taken from vigorously growing liquid cultures always showed continuous cell proliferation even when carried through successive subcultures over periods of several months. Further, when such subcultures were used to inoculate test-tube cultures and growth in darkness was followed by colorimeter readings, it was found that the growth rate had increased to 0.39 and no longer responded to added low illumination. Such "dark-adapted" cultures with increased growth rate in the dark and loss of response to added low illumination were obtained consistently in five different attempts.

Some insight into the locus of the light effect is provided by cell-size measurements. Cultures grown photosynthetically at light saturation have a mean cell volume of about 500 μ^3; cultures grown in the dark on glucose have a mean cell volume of about 2500 μ^3, decreasing to about 1500 μ^3 with dark adaptation. As is shown by iodine staining, the dark-grown cells contain greater amounts of starch. There appears to be no difficulty in carbon assimilation from glucose in the dark. The light stimulation must affect the specific synthesis of some key material required for cell division. Whether this synthesis is aided by a very slow turning of the photosynthetic cycle or by a photoprocess other than photosynthesis is not clear from the evidence at hand. Various extracts obtained from algae, liver, and yeast were ineffective in stimulating dark growth.

It is concluded that a special effect of light is observable in the growth of the Emerson strain of *Chlorella vulgaris* but not in the growth of other related algae. The effect is a transitory one as seen in a total culture, probably as a result of adaptive phenomena or the selection of variants from the original population. It is a stimulatory effect rather than an absolute requirement. There is as yet no evidence that it involves a photoprocess other than photosynthesis.

Nutritional Mutation in Chlamydomonas [2]

Donald F. Wetherell and Robert W. Krauss

The methods and introductory stages of a study designed to obtain information concerning biochemical mutations in unicellular green algae were discussed previously (Year Book No. 53, 1953–1954, pp. 180–182). Experiments with X-ray-induced mutants of *Chlamydomonas* have been continued with a view to the identification of both the physiological aberrations produced and the mechanism by which these aberrations are transmitted.

A total of 484 isolates from the irradiated material of *C. eugametos* have been screened for induced nutritional changes. Of these isolates, 297 formed subnormal-appearing colonies on complete medium immediately after irradiation and were therefore considered most likely to demonstrate identifiable biochemical mutations. The remaining 187 isolates produced normal-appearing colonies on complete medium and were not expected to be as likely a population for subsequent screening. Approximately 25 per cent of each group, however, showed physiological changes re-

[2] This work is being done at the University of Maryland.

flected as aberrant growth curves. The most common change observed was a pronounced lag before the occurrence of growth on minimal medium but little or no lag on complex media. An additional 10 per cent of each group proved to be morphologically altered as well. The principal morphological change was loss of motility.

The large number of nutritional aberrants revealed in the initial screening were characterized by a high rate of reversion or recovery to typical normal growth on minimal medium. Of 100 nutritional aberrants which appeared to carry inheritable mutations, 78 have recovered in subsequent tests. This phenomenon suggests either a highly unstable type of mutation or a progressive repair of a damaged cytoplasmic component which is not achieved until many generations of slow-growing daughter cells have been produced. Twenty-two more stable isolates have been screened to determine the component in the complete medium which is necessary to replace that lost from the normal metabolic system. Five of these were found to grow slowly in all media tested, i.e., no exogenous repair of the damaged metabolism was possible. Four others are growth-inhibited on media containing sugars or organic acids, but will grow normally on complex media or a vitamin supplement. One mutant will grow equally well when either succinic, fumaric, pyruvic, citric, or acetic acid is supplied in light. Eleven are vitamin-requiring mutants. Of those tested for individual vitamins, nine require thiamine or choline or both.

Work has also begun on the next phase of the study, which is concerned with the inheritance of the mutation and the production of clones with a broad spectrum of nutritional modifications. Four nutritional mutants have been successfully mated with normal cells. Two of these, which require thiamine or choline, yield a 1:1 segregation of normal and mutant cells. Another consistently produces one large normal colony, one weak colony, and two dead cells from the products of zygote division. The matings of the fourth mutant produce zygotes that germinate poorly. All the cells which are produced are nonviable. In such mutants, chromosome aberrations which are incompatible at meiosis may be the cause of abnormal segregation.

An effort was made to obtain more mutants which had specific requirements for organic carbon. Cells were irradiated, incubated in light for 24 hours to overcome phenomic lag, and plated on complete medium. The plates were placed either in darkness or in the light. Those in the light were maintained in a CO_2-free atmosphere. In both cases photosynthesis was blocked. Over two million irradiated cells were treated in this way. In no case did the cells divide more than twice. When small colonies were permitted to develop before being transferred to the nonphotosynthetic chambers, growth was still halted after transfer. On return to conditions where photosynthesis could take place, growth was resumed. Thus far no mutant has been obtained which can grow under conditions that do not permit photosynthesis.

A modification of this approach is obtained by incubating irradiated cells on a complete medium containing a metabolic inhibitor at a level which just inhibits growth in control cells. Ten isolates have been obtained which show a peculiar capacity for growth in the presence of arsenate. The mechanism of resistance has not been investigated.

The sensitivity of the direct screening method, in which the growth curves of progeny from irradiated cells are compared with those of the wild type, has permitted detection of a high frequency of nutritional aberrations. It is difficult to explain the repeated occurrence of such mutants as those requiring thiamine and choline. It is not likely that all are mutants of the same locus. It is more likely that these mutants represent a type of heritable damage to reactions deep in the metabolic network where a certain amount of compensation can take place along alternative

pathways, thus permitting gradual and temporary recovery of synthetic capacity during the incubation period. The recent work showing the chromosome number of *Chlamydomonas eugametos* to be ca. $n=36$, in contrast to $n=18$ for *C. Reinhardii,* makes it tempting to consider *C. eugametos* a polyploid in which some gene duplication is still present. (Comparison of lethal dose for the two species, however, shows that *C. eugametos* is only 1.2 times as resistant to X-irradiation as is *C. Reinhardii.*) Mutation of a locus in these segments may give rise to strains much weakened in synthetic capacity, yet the presence of an undamaged allele would be sufficient to permit survival. The phenomenon of leakage described by Bonner is another possible cause for the observed behavior. Finally, the possibility of generalized cytoplasmic damage must also be considered. Although choline and thiamine do not stimulate the growth of the control strain, they may prove effective for mutants by virtue of a stimulation of certain key reactions which in turn permit genetically damaged cells of different kinds to approach normal growth because of a general increase in enzyme or precursor synthesis.

EXPERIMENTAL TAXONOMY

Review of Principles

Occasionally during the course of a long-range program it is desirable to take stock of its current status, to review the principles that sustain it, and to express the aspirations for the future. The following is intended as such a broad review.

The primary subjects of investigation in the experimental taxonomy program are the forces and mechanisms that control and regulate the evolution of natural populations, ecological races, and species of various order, and enable them to live in the various niches of their respective natural environments. The program is necessarily limited to those evolutionary products that are most amenable to experimental study. It is also recognized that the controlling and regulating mechanisms that govern natural units differ from step to step in the evolutionary hierarchy, and that consequently various kinds of systematic entities must be studied and compared.

The forces that operate on the organism are selective, and some are internal while others are external. The internal selective forces fit the processes and mechanisms together into a workable combination. They operate through the mechanisms of single genes, of groups of genes, of whole chromosomes, or of chromosomal complexes that govern all the processes of development and growth.

Although the exact nature of the gene is not known, we are beginning to understand some general features of the intricate gene systems that control characters by which we recognize natural evolutionary units. We do not yet understand, however, the many biochemical and physiological processes that intervene between gene systems and the characters they control.

The external selective forces operate through the mechanism of the environment in which the plant grows, but their effects may penetrate internally by influencing the biochemical-physiological balances that determine the plant's metabolism. Such external factors as temperature, for example, may greatly influence the expression of a character in different environments. For certain characters, evidence is now accumulating from transplant experiments that "spare" genes may exist that operate only under certain environmental conditions. It is also indicated that somewhat different complements of genes may influence the expression of characters in different environments. The extent of such modifications in expression has only recently become known through an analysis of the responses at the three altitudinal transplant stations of a cloned F_2 population of a cross between ecologically contrasting races of *Potentilla glandulosa.*

As a working principle, most of the tools available to biology may be utilized in experimental taxonomy in order to gain a better understanding of how living things evolve, function, and fit themselves to the available environments. From this viewpoint the study of the morphological appearance and the geographic-ecological distribution of the naturally occurring systematic entities is essential for a grasp of the broad sweep of plant evolution.

The approaches of genetics and cytology are utilized to study the gene systems that basically control the appearance of populations, races, and species and their fitness to environment. The gene systems are taken apart and put together into new combinations through crossings, and the responses of the recombination products are studied in different environments. The transplant stations are useful as a coarse screen to indicate broad differentiation in environmental fitness among the recombined products.

In such a study on *Potentilla glandulosa* a new comprehension of the complexity of the genetic systems controlling the metabolism of a plant has been glimpsed. The complexity will doubtless be clarified as one learns to understand the biochemical and physiological steps intervening between gene and character.

Experiments under controlled conditions of temperature and light, such as have previously been performed in the Earhart Laboratory at the California Institute of Technology (Year Books No. 43, 1943–1944, pp. 75–79; No. 50, 1950–1951, pp. 99–104), have pointed toward the significance of certain environmental factors, such as the relation between day and night temperatures during the growth period, which partly determine the success of a plant in a certain kind of environment.

It should be possible to come a step closer to a unified understanding of why certain plants respond as they do in certain environments through detailed and recorded study of the individual physiological processes under carefully controlled and known environmental conditions. When such information is related to the hereditary mechanism of the plant, we shall probably be able to approach more nearly a unitary concept of life processes. Such a concept would envision the genes as working through biochemical-physiological processes. The resultant of these processes under various conditions would account for the plant's morphological expression in contrasting environments. It would also account for the fitness of the race and the species to its environment, and ultimately even for the barriers that separate species, which are the basis of diversification in organic evolution.

In order to approach the comprehensive objective of such investigations with some exactitude, it will be necessary to have available for experimental purposes an organism that evolutionarily is relatively simple. Such an organism should be a diploid species having a simple chromosomal mechanism and distinct morphological variations that can be used as markers in genetic investigations. It should be an organism that is perennial, that can be cloned, and that has evolved races fitted for contrasting environments, but that has not evolved serious barriers to interbreeding.

Very few plants with all these characteristics exist, but among the groups more recently tried, the *Mimulus cardinalis-lewisii* complex fairly well fulfills these exacting requirements. The recent experiments with the Lemnaceae demonstrate the value of these minute higher plants for some phases of experimental study, especially for comparative physiology. This group of plants, however, is not suited for genetic experiments.

The central laboratory and gardens of the Department at Stanford facilitate the study of racial differences and the initial genetic analysis in one standard environment. The altitudinal transplant stations offer opportunities for the genetic analysis of cloned hybrids in contrasting environments, and the environments of the sta-

tions have previously been calibrated in terms of plant responses through investigations on natural races of many species of plants.

Studies at the altitudinal stations linked with controlled laboratory studies such as can be conducted at the Earhart Laboratory of the California Institute of Technology make it possible to select individuals that in their responses show major physiological differences among samples of plants. Finally, the development of apparatus for the quantitative comparison of metabolic rate of respiration and photosynthesis under controlled conditions will make possible the study of the individual physiological processes in relation to known genetic characteristics of plants whose responses are being tested at the altitudinal stations.

Poa Investigations

Jens Clausen, William M. Hiesey, and Malcolm A. Nobs

During the past year, seed of apomictic hybrid lines and of their parental species were sent to the U. S. Agricultural Research Service in preparation for preliminary regional tests being co-ordinated by Dr. A. A. Hanson. At some testing stations the seeds were sown in the spring of 1955, and at the others they will be sown during the fall of 1955 and the spring of 1956. The purpose of these preliminary tests is to obtain information on the range of tolerance, failures, and other responses of these lines in highly different environments, so that the behavior pattern of each strain can be ascertained and regions for which it is fitted may be predicted.

The apomictic strains of *Poa* are ideally suited for large-scale transplantation as seed clones to many environments, some of which are on different continents. Very little information is available on the climatic responses of genetically identical plants in environments as different as those found along the Pacific coast, as compared with those in the northeastern part of the drainage basin of the Mississippi River.

The Agricultural Research Service has arranged for tests with fourteen of its collaborators: Dr. H. B. Musser, Pennsylvania State University, State College, Pennsylvania; Dr. T. Jackson Smith, Agricultural Experiment Station, Blacksburg, Virginia; Dr. E. L. Nielsen, University of Wisconsin, Madison, Wisconsin; Dr. H. H. Kramer, Purdue University, Lafayette, Indiana; Dr. R. R. Buckner, Lexington, Kentucky; Dr. E. Marion Brown, Agricultural Experiment Station, Columbia, Missouri; Dr. H. D. Ellzey, Jr., Franklinton, Louisiana; Dr. K. L. Anderson, Agricultural Experiment Station, Manhattan, Kansas; Dr. J. R. Harlan, Oklahoma A. and M. College, Stillwater, Oklahoma; Dr. R. E. Stitt, Agricultural Experiment Station, Bozeman, Montana; Dr. William McGinnies, Great Basin Research Center, Ephraim, Utah; Dr. Alvin T. Bleak, Agricultural Experiment Station, University of Nevada, Reno, Nevada; Dr. H. H. Rampton, Agricultural Experiment Station, Corvallis, Oregon; Dr. D. R. Cornelius, Forest and Range Experiment Station, Berkeley, California.

When the plantings become established, these stations are to be visited by members of our staff, probably in company with Dr. A. A. Hanson of the Agricultural Research Service.

In addition to these plantings, a selection of hybrid and parental strains have also been established in Minnesota by Dr. H. L. Thomas, University of Minnesota, Minneapolis, and in Texas by Dr. Johnny T. Davis, Texas Research Foundation, Renner. Both Dr. Thomas and Dr. Davis plan to initiate new crossings for the purpose of developing strains fitted to their respective local areas.

The greatest number of seed-producing strains are being grown by the U. S. Soil Conservation Service at their Pullman, Washington, Nursery. At the Pleasanton Nursery, California, three strains most likely to be of interest to California are now in successful seed production in approximately half-acre plots. In addition,

the Ferry-Morse Seed Company, of Mountain View, California, has a similar seed planting of a fourth strain also intended for California. The Soil Conservation Service plans to establish field trial plots at nine places in the far western states: Temecula in southern California; King City and Sunol in central California; Butte Valley in the northern Sierra Nevada; Bridgeport in the Great Basin area of California; Pendleton in northeastern Oregon; Lind on the Columbia River plains, Washington; Aberdeen and Tetonia in southeastern Idaho.

The planting at Lind was seeded during the spring of 1955. Extensive testing in many places is necessary in the far western states because of the highly varied topographic, climatic, and soil conditions, and also because a greater percentage of the strains are expected to fit the western conditions than those of the central states. Dr. A. L. Hafenrichter, Mr. John L. Schwendiman, and Mr. H. W. Miller are co-ordinating the Soil Conservation Service plantings in co-operation with state agencies.

During the spring of 1955, plants of each hybrid line and each parental strain were cloned and planted at the three altitudes of Stanford, Mather, and Timberline. Many of the newer strains have not hitherto been tested at our transplant stations. Hybrid and parental lines have also been established in dense row field plantings at Stanford for the purpose of observing closely their behavior under such cultural conditions. The co-operation of the Soil Conservation Service, the Agricultural Research Service, and other agencies thus permits testing an assortment of approximately 42 apomictic strains in about 28 different environments besides our Department's three altitudinal stations.

The co-operative program with Purdue University, Lafayette, Indiana, is now well under way. The purpose of this program is to utilize the method of interspecific crossing of predominantly asexually reproducing apomictic species for developing strains of *Poa* suitable for the midwestern region of the United States. The work is being supervised by Dr. H. H. Kramer, of the Department of Agronomy. Mr. Paul L. Pfahler, a graduate student, is the first holder of a student fellowship being supported jointly by Purdue University and the Carnegie Institution of Washington. He has started work both at Purdue and at Stanford.

During 1954 the hybrid *Poa* lines then available, the parental strains, and selected commercial strains of *Poa pratensis* currently being used in the midwestern states were space planted in replicated plots near Lafayette. During May 1955, this planting was visited by Clausen and notes were taken by him together with Dr. Kramer and Mr. Pfahler.

The parental populations of *Poa ampla* which are vigorous in the western states died at Purdue except for a few weak surviving individuals. Lines of *P. scabrella* successful in the lowland regions of California failed completely. Parental lines of *P. pratensis* generally survived, but they were weak as compared with commercial strains of *P. pratensis* used in the midwestern area.

Two noteworthy exceptions were a line of *Poa pratensis* from Newport, on the Oregon coast, and another from near Leevining, California, in the Great Basin area. Both were vigorous and aggressive at Purdue, and the Newport strain compared favorably in such characteristics as leafiness with local commercial strains. In the Pacific states the Newport and Leevining strains have proved to be among the most tolerant to extreme climatic contrasts. The Newport strain survives at Timberline station at 10,000 feet and surpasses in total growth even the alpine strain native to this area. It is the only plant from the immediate coast that has successfully survived at Timberline over a period of years. It was among the most vigorous strains in Dr. J. W. Gregor's field at Corstorphine in Scotland at 59° north latitude, and in Dr. Paul Solberg's plantings at Volbu,

Norway, at 61° north latitude and 1500 feet altitude.

The responses of the *Poa* lines at Purdue suggest that the environmental differences, as they affect these strains, are consistently greater between the north central and the far western states than they are between central California and the Pacific Northwest. Moreover, growth of the various apomictic strains is more alike as between northwestern Europe and western North America than as between either of these two places and the north central region of the United States.

This observation is of interest in its apparent contradiction of the fact that several commercial grass strains are grown successfully both in the Pacific Northwest and in the midwestern states, for much of the grass seed sown in the central states is harvested in the west. Spaced plantings of the same commercial strains of *Poa pratensis* at Pullman and at Purdue indicate, however, that the strains are highly variable and are composed of a large number of distinct biotypes.

A direct comparison was made on the Delta strain of *Poa pratensis,* which originated from collections by Dr. L. E. Kirk made in Saskatchewan and northern Alberta approximately forty years ago. One highly apomictic individual of this strain was used extensively in our crossings with *P. ampla* and *P. scabrella,* and the progeny of this plant have been referred to by us as the Athabaska line, after the general region from which the Delta strain originated.

The Athabaska line extracted from the Delta is highly uniform as compared with plantings of the variable commercial Delta strain. Certain individuals within the Delta strain, however, resemble the Athabaska type. In the states bordering the Pacific, the vigor and productivity of the Athabaska line is comparable with that of commercial Delta, but not so at Purdue, where the Athabaska grows poorly, is highly stemmy, and is uniformly of low vigor. At Purdue, however, the better plants of commercial Delta ranged among the most vigorous, although there the strain contained individuals ranging from high to low vigor, and from leafy to stemmy. Other space-planted commercial strains of *Poa pratensis* have shown equal variability in agronomic and other characters both at Pullman and at Purdue.

It seems clear, therefore, that seed of commercial varieties can be produced in one climatic region and used in a very different one because such strains are composed of intermixtures of many biotypes. When plants are grown in close competition, as in most agricultural plantings, only the most vigorous succeed, and the weak individuals remain unnoticed. The sample of biotypes that thrives in one region differs, therefore, from the sample that thrives in another. For this reason the composition of the strain will differ from region to region, although it is not possible to detect such differences unless the plants are space planted and detailed comparative notes are taken.

An apomictic line, on the other hand, contains only one vigorous asexually reproducing biotype in addition to a few weak sexual aberrants. The range of tolerance of such a line is determined by the range of tolerance of its single apomictic biotype. For this reason the tolerance of the apomictic line may be more limited than the combined tolerances of the many biotypes of which a sexual strain is composed.

Certain apomicts nevertheless have a remarkable tolerance, for instance the *Poa pratensis* line from Newport, mentioned above, and the 4694-8 line of *P. scabrella-pratensis,* a cross between a *P. scabrella* from the southern California Coast Range and the Athabaska line of *pratensis.* This latter hybrid survives with approximately the same vigor in all the environments tested between such extremes as Stanford, California; Uppsala, Sweden; and Purdue, Indiana. A characteristic of the tolerant apomicts is that they modify little from environment to environment, whereas the

more specialized strains become highly modified.

Most of the interspecific hybrid lines of *Poa* were weak at Purdue, even though some were more vigorous there than either parent. The *P. ampla-alpigena* combinations were moderately successful and of fair quality, although both parents were definitely unsuccessful. Other lines, however, originating from the cross between *P. ampla* from Albion in the Palouse Prairie and *P. pratensis* from Mather in the Sierra Nevada, were distinctly weak. Apparently it is not the cold winters at Purdue that are unfavorable for the growth of the hybrids of this parentage, for they survive with relative vigor at the Timberline transplant station. Both parents, however, originate from climates having a growing season of warm days combined with cold night temperatures. It is probable that the warm nights in Indiana are deleterious to this group of strains.

The responses of the *Poa* hybrids at Purdue may be indicative of growth to be expected in other midwestern localities. Preliminary notes kindly supplied by Dr. Thomas, of the Department of Agronomy of the University of Minnesota, suggest that there is some similarity in responses to those observed at Purdue. Several hybrid lines, however, survived with considerable vigor at Minnesota which have been weak at Purdue. One may expect other unpredictable responses as the lines become established in the regions covered by the screening tests of the Agricultural Research Service. Predictions are impossible at present because plants of genetically identical biotypes have not yet been tested in environments so different.

Chromosome Numbers of Hybrid Poa Lines

Lois M. Cox and Jens Clausen

The significance of the study of chromosome numbers of hybrid lines in relation to their parents has been reviewed in Year Book No. 53, 1953–1954 (pp. 156–157). Knowledge of the chromosome number aids in calculating the gross proportion of parental chromosomes that entered the first-generation hybrid and in assessing readjustments that occurred in the complement as the strain stabilized. Such information, therefore, aids materially in interpreting morphological-agronomic characteristics and the environmental responses of the various hybrid lines.

This study has been considerably advanced during the current year, so that chromosome numbers of all but one of the lines used in the regional tests described above are now known. The newly determined chromosome numbers are listed in table 2, and for the sake of completeness counts reported last year (*loc. cit.,* p. 156, table 2) are included. These data reveal some points of special interest and have considerable current reference value for our collaborators.

For simplicity in comparing the hybrids with the parents, the highly polyploid parental species will in the following be referred to as "diploids." The hybrids that arose from two parental gametes having a reduced number of chromosomes, and accordingly having numbers between those of the parents, will also be considered "diploids." Other hybrids, however, that appear to have arisen from one unreduced and one reduced gamete will be referred to as "triploids."

Using this terminology, table 2 shows, for example, that from a sexual diploid 70-chromosome F_1 hybrid (4535-52) between *Poa ampla,* Albion, and *P. pratensis,* Mather, three new apomictic lines were obtained in the F_2 (lines 13833-211, 13833-311, and 13833-701). All three of these F_2 lines had increased their chromosome numbers from the diploid to the triploid level, having numbers ranging from 98 to 100. In this case the increase in chromosome number of these three lines did not strikingly change their morphological appearance as compared with their diploid F_1 parent; they continued to remain simi-

TABLE 2

Somatic chromosome numbers in 54 apomictic hybrid lines of Poa and their parents

Parent F_1 of line: line no. and $2n$	Hybrid: Line no.	Generation	$2n$
Poa ampla, Albion, $2n=63$, × *pratensis alpigena,* Lapland, $2n=74$:			
4273-8, 73	4683-1	F_2	70
	4683-4	F_2	63
4273-9, 63	4684-1	F_2	ca. 106
	4684-5	F_2	93
	13945-410	F_3	ca. 77
4273-13, 70	13536-11	F_2	66
	13948-204	F_3	96–97
Poa ampla, Albion, $2n=63$, × *pratensis,* Mather, $2n=68$:			
	4535-6	F_1	95–97
	4535-26	F_1	ca. 100
	4535-45	F_1	90–92
4535-2, 96	5971-208	F_3	75–77
	5971-408	F_3	83–85
4535-4, 63	13775-211	F_2	66–67
	13775-212	F_2	56
4535-5, 93	13823-706	F_2	55–57
4535-46, 104	5979-408	F_3	ca. 89
4535-51, 117	13832-409	F_2	ca. 82
4535-52, 70	13833-211	F_2	99
	13833-311	F_2	ca. 98
	13833-701	F_2	ca. 100
Poa ampla, Albion, $2n=63$, × *pratensis,* Athabaska, $2n=70$:			
	4729-2	F_1	103
	4729-11	F_1	78
Poa ampla, Kahlotus, $2n=64$, × *pratensis,* Athabaska, $2n=70$:			
4537-9, 83	13783-29	F_2	93
	13783-33	F_2	68
	13783-208	F_2	ca. 70
	13783-301	F_2	80
	13783-507	F_2	70–71
	5186-20	F_2	87
	5186-21	F_2	109±5
	5186-23	F_2	ca. 84
	5186-123	F_2	70±2
	5186-309	F_2	100
	5186-311	F_2	84–85
	5186-323	F_2	81
	5186-418	F_2	80
	5186-701	F_2	ca. 86
	5186-702	F_2	ca. 75
Poa ampla, Heise, $2n=70$, × *pratensis,* Newport, $2n=81$:			
4731-2, 75	4804-523	F_2	ca. 100
Poa ampla, Albion, $2n=63$, × *compressa,* Chorsum, $2n=50$:			
4274-3, 87	13949-410	F_3	ca. 82
Poa [*ampla,* Albion, $2n=63$, × *compressa,* Chorsum, $2n=50$] × *alpigena,* Lapland, $2n=74$:			
4274-3, 87	13949-308	F_1	ca. 84
Poa scabrella, Las Posas, $2n=82$–84, × *ampla,* Kahlotus, $2n=63$:			
	4569-1	F_1	ca. 74
	4569-2	F_1	ca. 73
Poa [*scabrella,* Las Posas, $2n=82$–84, × *pratensis,* Athabaska, $2n=70$] × *ampla,* Albion, $2n=63$:			
4699-6, 63	13942-203	F_2	62
Poa scabrella, Las Posas, $2n=82$–84, × *pratensis,* Athabaska, $2n=70$:			
4553-2, 70	4694-8	F_2	ca. 69
Poa scabrella, Las Posas, $2n=82$–84, × *pratensis,* Leevining, $2n=68$:			
	4559-2	F_1	ca. 75
4559-3, 76±2	4724-4	F_2	99–102
	13548-10	F_2	ca. 64
Poa scabrella, Las Posas, $2n=82$–84, × *pratensis,* Mather, $2n=68$:			
	4557-3	F_1	75
4557-4, 64–66	4706-1	F_2	64±1
4557-10, 74	4711-3	F_2	66–68
Poa [*scabrella,* Las Posas, $2n=82$–84, × *pratensis,* Mather, $2n=68$] × *alpigena,* Lapland, $2n=74$:			
4557-10, 74	13838-305	F_1	ca. 101
	13838-513	F_1	93
Poa scabrella, Watsonville, $2n=84$, × *pratensis,* Athabaska, $2n=70$:			
4561-1, 71	4726-3	F_2	65±2
Poa canbyi, Blue Mountains, $2n=84$, × *pratensis,* Athabaska, $2n=70$:			
4263-1, 77	4692-6	F_2	ca. 66

lar to *P. pratensis,* although they bloom later and are more leafy than *pratensis.*

These triploid F_2 lines from a diploid F_1 are morphologically very different from the equally triploid apomictic lines of the same cross that originated from triploid F_1's (4535-6, 4535-26, and 4535-45, $2n=92$ to 100). These F_1 lines resemble *Poa ampla* more and apparently have received a preponderance of *ampla* chromosomes.

Some of the F_2 lines deviate very little in chromosome number from their parental F_1's. The 4694-8 *Poa scabrella-pratensis* F_2 line changed only from $2n=70$ to $2n=69$, and the 13942-203 *P. scabrella-pratensis-ampla* F_2 line from $2n=63$ to $2n=62$. Although in these two cases the chromosome numbers were almost unchanged, the gross morphologies of the apomictic F_2 lines were in sharp contrast with the characters of the F_1 lines from which they had been derived.

By contrast, examples can be cited of strains that morphologically are exceedingly similar but chromosomally are quite distinct. Among these are the lines 13783-33 and 13783-301 of *Poa ampla-pratensis,* Kahlotus-Athabaska, which are nearly indistinguishable except in their chromosome numbers of $2n=68$ and 80, respectively.

Similarly, two triple hybrids of *Poa scabrella-pratensis-alpigena,* the lines 13833-305 and -513, are morphologically indistinguishable although they differ chromosomally in having respectively $2n=$ ca. 101 and 93. Both arose from the 74-chromosome 4557-10, a *scabrella-pratensis* hybrid which, in addition, gave rise to the 66-chromosome line 4711-3 without the aid of *alpigena* pollen. All three lines from the 4557-10 parent appear agronomically promising although in different regions.

The most extensive chromosomal evidence comes from 15 apomictic F_2 lines, all arising from the sexual F_1 plant 4537-9 of *Poa ampla-pratensis,* Kahlotus-Athabaska, having $2n=$ ca. 83 chromosomes. The first 5 lines of this parentage were selected at Pullman, the following 8 at Stanford, and the last 2 by Dr. P. J. Watson, of the Scottish Plant Breeding Station at Corstorphine, Edinburgh, Scotland. All 15 F_2 lines were derived from seeds of the same seed bag harvested from the F_1 plant at Stanford, but were grown and selected at these three stations, which have very different climates. The 15 lines and the parental species are now being grown together for comparison at both Stanford and Pullman.

Chromosomally only 3 of the 15 lines rose to the triploid level, $2n=93$ to 109, whereas 5 dropped to the diploid level, $2n=68$ to 75. The other 7 lines differed only slightly in chromosome numbers from the $2n=83$ of the parental F_1, which is halfway between the "diploid" and "triploid" levels. In morphology and general responses these 15 lines are highly divergent.

Studies on the Lemnaceae

Elias Landolt

The study of the biosystematic structure of the aquatic plant family Lemnaceae initiated last year (see Year Book No. 53, 1953–1954, pp. 159–162) was continued through February 1955. The successful growth of a number of strains of different species of this family in pure culture in test tubes and flasks, as described in last year's report, provided a most fruitful means for studying the comparative physiology under controlled conditions of forms originating from widely divergent environments and climates.

Part of the study, especially the initial phases, was conducted at Stanford in four cabinets maintained at constant temperatures and with a controlled source of artificial light. An expanded program was carried on from October 1, 1954 to January 31, 1955 at the Earhart Laboratory of the California Institute of Technology, with the unusual facilities provided there for studies under controlled environments.

As many as a thousand Erlenmeyer flasks containing pure cultures could be grown simultaneously under controlled

conditions of light and temperature. Periods ranging from two weeks to a month were found to be sufficient for the completion of one experimental run of these fast-growing plants under different treatments. The data from this comparative physiological study, in conjunction with observations in the field at the original sites of collection of many of the strains under investigation in pure culture, provide a substantial body of information on the biological relationships among the Lemnaceae.

The following species were included in the study: *Spirodela polyrhiza, S. oligorhiza, Lemna valdiviana* (including *L. minima*), *L. perpusilla* (including *L. paucicostata*), *L. minor, L. gibba, L. trisulca, Wolffia columbiana, W. punctata,* and *W. arhiza.* Most of these species were collected in California, each being represented by several strains, but additional strains of some species from other parts of the United States and from Europe were also grown for comparison. *Wolffiella lingulata,* a native of California occurring frequently in canals, ponds, and watercourses of the San Joaquin Valley and the coast region south of Santa Cruz, has not thus far been successfully transferred to pure cultures and accordingly was not included in the physiological investigations.

In the studies in the Earhart Laboratory, cultures of cloned individuals of various strains of the different species were grown at different temperatures (4°, 7°, 14°, 26°, 30° C) and at different intensities (90, 220, and 600 foot-candles) of artificial fluorescent light. Some cultures were grown also in complete darkness with organic nutrients supplied to the media. The rate of increase in number of fronds per unit time was used as a comparative measure of growth rate.

Eight key cloned strains were tested under all the combinations of conditions tried, and 42 additional strains under only selected combinations of conditions. Hutner's solution was used as the basic culture medium, and sugar was added in certain experiments. Yeast extract and casein hydrolyzate were likewise added to cultures grown in complete darkness. The addition of sugar increases the growth rate of every strain both in light and in darkness (cf. previous Year Book), but in light the addition of yeast extract and casein has no influence on the growth of most species. However, species such as *Wolffia punctata* and *Lemna trisulca* that grow either wholly or nearly submerged in the culture medium are stimulated by the addition of yeast extract and casein even in the presence of light.

The growth rates of cultures in solutions without sugar show about the same temperature optimum for all species and strains that were tested, namely about 26° C. Strains and species differ markedly, however, in their relative rates of growth. In cultures without sugar, the following differences between rates of growth were observed:

1. The growth rate at the optimal temperature may vary with the strain and especially with the species. At 26° C and at a light intensity of either 90 or 220 foot-candles, the fastest-growing strain among all the species tested has nearly twice the growth rate of the slowest.

2. Species may differ with respect to their tolerance to high temperatures. Strains of some species fail to grow at 32° C, whereas strains of others grow successfully up to 38° C at the same light intensity.

3. Strains and species may differ markedly with respect to their growth behavior at cool temperatures. Some species, including *Spirodela polyrhiza, Wolffia,* and certain strains of *Lemna minor,* form special kinds of resting buds, or turions, which sink to the bottom of the flask. Under optimal nutrient conditions the temperature at which this response begins to occur may be as high as 14° C for *Spirodela polyrhiza,* or as low as 7° C for some strains of *Lemna minor.* When mineral nutrients become exhausted, as in old cul-

tures, the same strains may also form turions at higher temperatures.

Another group of Lemnaceae, which includes *Lemna gibba* and certain strains of *L. minor,* is non-turion-forming and can maintain active normal growth of fronds at temperatures as low as 4° C. Still another category of strains, which includes forms of *L. valdiviana* and *L. perpusilla,* is able to maintain some growth at temperatures lower than 14° C, but produces abnormally small fronds and otherwise shows symptoms of irregular development and poor growth. Transitions between the three types of response have also been found.

4. Different strains reach light saturation at different intensities of light. Among 16 strains tested, one had reached this point at 600 foot-candles, whereas in a few other strains the saturation point was found to be higher than 1000 foot-candles. In these experiments with artificial light, a day length of 16 hours was used.

One of the most interesting results of these studies is the relation found between the rate of growth in darkness of various species and strains (with sugar, casein hydrolyzate, and yeast extract added to the medium) and the rate of growth in light of the same clones (either with or without sugar). The increase in growth rate in light due to the addition of sugar is highly correlated with the growth rate of the same clones in darkness.

The species and strains differ markedly in their rates of growth in the dark, some growing as much as five times faster than others at the same temperature. The data show conclusively that the growth of a given strain supplied with sugar and exposed to light consists of gains made independently (*a*) through the absorption of carbohydrate from the culture medium and (*b*) through assimilation by photosynthesis.

The data fail to demonstrate any significant differences in temperature response of forms of the same species from ecologically distinct environments. Strains of *Spirodela,* for example, obtained from cool coastal areas of Oregon and from the hot Central Valley of California have about the same growth rates at the various temperatures tried. On the other hand, distinct species from the same locations in the Central Valley may show quite different growth responses.

There is a marked tendency for various strains of the same species of Lemnaceae to respond in a similar manner, but strains of distinct species show marked differences in their patterns of growth. For example, strains of *Lemna valdiviana* from moderately diverse climates are unable to tolerate continuous high temperatures of 32° C, whereas the strains of *Spirodela polyrhiza* grow successfully at 38° C. In media containing sugar, casein hydrolyzate, and yeast extract, and in the absence of light, *L. minor* grows relatively slowly, whereas *L. perpusilla* and *S. polyrhiza* grow rapidly.

These facts suggest that during the course of their evolution the Lemnaceae have become differentiated primarily at the species level rather than at a subspecific level. This pattern of differentiation is in contrast with that shown by herbaceous and woody species having a wide geographic distribution, in which the existence of well-defined climatic races or ecotypes has been demonstrated. The pattern of evolution in the Lemnaceae may possibly be related to their mode of growth in an aquatic environment and to their relatively simple anatomical structure.

Six strains of *Lemna minor* and *L. perpusilla* were found to flower under some of the controlled conditions under which they were grown. Other strains of the same species and from similar climatic regions failed to produce flowers under the same conditions.

Periodic field observations of naturally occurring colonies of Lemnaceae at selected sites including the coast, the Central Valley, and the Great Basin areas of central California revealed that the various species fluctuated widely in seasonal activity in the different localities. The duration and

extent of flowering observed in these natural environments also differed greatly from locality to locality. At some sites flowering was not found, whereas at others fronds bearing flowers could be found almost throughout the entire year. There seems to be no close correlation between climate and flowering, a fact that suggests that the capacity to flower may not be essential for the survival of some species.

Certain strains of *Lemna gibba* and *L. perpusilla* were found regularly to set fruit, but otherwise the occurrence of seed in the Lemnaceae appeared to be extremely rare. *Lemna gibba* and *L. perpusilla* are the only species found to occur in temporarily flooded areas such as rice fields, and the production of seeds may be their only means of survival during the intervening dry periods.

The complete analysis of the data that have been obtained on the Lemnaceae will require some time. It is planned to publish the results.

Physiology of Climatic Races

Harold W. Milner and William M. Hiesey

The apparatus for the quantitative measurement of photosynthesis and respiration under controlled light intensity, temperature, and humidity, described in previous Year Books (No. 52, pp. 176–178; No. 53, p. 152), has been further developed. The contemplated rearrangements of the parts have been made, so that nearly all the gas volume of the system is under thermostatic control, less than 2 per cent being subject to the influence of changes in room temperature. Precise ($\pm 0.05°$ C) control of the air temperature in the housing for the gas injection and absorption mechanisms of the apparatus has been attained. The same narrow limits of temperature variation are maintained in the baths surrounding the plant chamber and dehumidifying unit.

Measurements of plant metabolism to the desired degree of accuracy have not yet been possible, but appear to be almost at hand. In short-time tests the response of the analyzers was satisfactory. A change of two parts per million in carbon dioxide concentration and of 0.02 per cent in oxygen content of the air in the system could be registered. In long runs, however, drifts in behavior of some electronic components of the control system made it impossible to measure accurately the changes in gas composition due to activity of the experimental plants. With the help of Mr. John F. Hansen, some of the electronic problems have already been solved, and redesign of additional circuits promises to yield the desired degree of precision in performance.

Improvements are being made in the devices for supplying carbon dioxide, hydrogen, and oxygen at atmospheric pressure to the injection pumps. A number of minor mechanical changes have increased the utility of the apparatus.

Over a hundred pure cultures of clones of strains and species of Lemnaceae isolated by Dr. Landolt are being maintained by periodical transfer. Growth studies on many of these strains were made by Dr. Landolt at the Earhart Laboratory. These studies, described in the preceding section of this report, reveal striking differences in the growth of the plants in response to changes in environmental conditions. It is planned to measure the rates of photosynthesis and respiration of the same strains of Lemnaceae in the new apparatus. Then there will be available comparable data on growth and on the photosynthetic and respiratory activity of plants growing under controlled conditions.

The long-range aim for the program on plant metabolism envisions three stages: (1) the broad screening of ecologically diverse strains, species, and hybrids for differences in response to the environments in the station gardens; (2) the study of their comparative growth in controlled environments; and (3) critical quantitative studies of their comparative metabolism in

the new apparatus. The Lemnaceae can serve well as pilot organisms in this physiological approach to studies in experimental taxonomy. The new apparatus is designed to meet the exacting requirements of the third and most important stage, not only in the study of Lemnaceae, but also in investigation of other plant groups suitable for experimentation.

Seasonal Periodicity in Mimulus

Malcolm A. Nobs

During the past year the seasonal periodicities of the parental forms and the first- and second-generation hybrids of *Mimulus cardinalis* and *M. lewisii* have been followed. These physiological differences as expressed in the lowland garden at Stanford are as striking as the differences in pollination mechanism and morphological characters reported last year (Year Book No. 53, 1953–1954, pp. 157–159).

Mimulus cardinalis, the lowland form from near Stanford, remains active throughout the year although during the winter it ceases flowering and is reduced to a robust rosette of fresh green leaves; it commences flowering again in late April. The alpine *M. lewisii* becomes dormant during the winter and remains in this condition until late spring, when it commences weak growth. It does not flower until June, nearly two months later than the lowland species; and after its initial flush of flowering it becomes semidormant.

The F_1 hybrids resemble the lowland parent most closely in their periodicity, remaining moderately active and strong throughout the year; their initial flowering is late as in *lewisii,* but the flowering continues during the summer as in *cardinalis.* The elements of the seasonal rhythms of the parental species have been completely recombined in the second-generation plants, and some plants exceed the parental extremes both in dormancy and activity and in early and late initial blooming.

A simple pilot experiment using supplementary light during the winter of 1954–1955 indicates that the period of illumination is an important contributing factor in the control of these seasonal growth patterns. Three identical samples of plants were taken from the outdoor nursery during the period of minimum activity in early January and exposed to three different conditions. Each of the three samples consisted of five plants of each parental species, one individual of which was replicated four times, and four replications each of two first-generation individuals.

Two samples were placed in a greenhouse in which the night temperatures were approximately 15° C and the day temperatures rose to about 22° in the afternoon. One of these was given supplementary light which increased the photoperiod to 15 hours, the other had the natural day length for the season. The third sample was held under natural outdoor nursery conditions.

The response in the greenhouse with supplementary light was immediate and striking. Within two weeks all the plants receiving supplementary light were in active growth, characterized by rapid internode elongation and leaf enlargement, and they were all in full flower within eight weeks. The appearance of the lowland form was vigorous, whereas that of the alpine was very weak.

The responses of the sample under greenhouse conditions with natural seasonal light corresponded closely to those under outdoor nursery conditions and in garden populations. *Mimulus cardinalis* responded most rapidly and commenced blooming at a day length of about 13 hours, only 2 days earlier than the nursery and garden material. In all three places having natural day length, *M. lewisii* remained essentially dormant until early April, when weak growth commenced and flowering occurred simultaneously at about 15 hours of daylight. In the greenhouse, with natural day length, the first-generation hybrids were extremely active vegetatively during the entire experiment, but flowered concurrently with the

outdoor nursery controls and garden plantings at about 15 hours of daylight.

Even more striking indications of the physiological differences between these two closely related species are found in their responses in the preliminary plantings at the mountain stations (Year Book No. 52, 1952–1953, p. 175). *Mimulus cardinalis* from the mild climate in the outer Coast Range thrives in the Stanford garden but was entirely eliminated during the first season at both Mather and Timberline. Replacements planted last year appear to be following the same pattern. *Mimulus lewisii,* on the other hand, a native of the slopes above the Timberline station, survives at Timberline but is greatly weakened at Mather and is so feeble at Stanford that a loss of over 75 per cent occurred during the first season.

The first-generation hybrids show a much broader tolerance than either parent, and survive in all three transplant environments. In the meadow garden at Timberline, however, the severe summer frosts prevent their flowering, whereas flowering is possible in a garden above the meadow on a slope facing south. It is as yet too early to evaluate the correlations between these physiological differences and the morphological characters. With such positive morphological markers and great differences in environmental responses, however, this group of plants appears exceptionally well fitted for transplant work, genetic analysis, and refined physiological studies.

Diploid, Tetraploid, and Hexaploid Hybrids of Achillea

Jens Claussen, William M. Hiesey, and Malcolm A. Nobs

The continued studies on the *Achillea millefolium* complex concern relationships at evolutionarily relatively complex levels. This large, circumboreal species group was discussed in detail by Dr. Ehrendorfer (Year Book No. 51, 1951–1952, pp. 125–131); it contains a vast array of ecological races belonging to a closely related group of species that chromosomally have evolved into a series of diploid ($n=9$), tetraploid ($n=18$), and hexaploid ($n=27$) species.

The accumulated data strongly suggest that a great deal of the basic evolutionary differentiation took place on the diploid level. The diploids are now restricted to the Old World, where they are represented by morphologically distinct forms that appear to have evolved strong barriers to interbreeeding. Two F_1 hybrids involving three distinct diploids were made during the summer of 1953 and have now reached maturity. These hybrids are *Achillea setacea* W. et K. × *A. asplenifolia* Vent., and *A. asplenifolia* Vent. × *A. tomentosa* L. They are so highly sterile that during two seasons of flowering no seed has been obtained either by self-pollination or by open pollination.

A triangle of hybrids between morphologically and ecologically contrasting races of the tetraploid *Achillea lanulosa* have now come into maturity in the garden at Stanford. The three races of this triangle are a tall salt-marsh form from Suisun Bay not far from San Francisco, a low, compacted maritime form from exposed coastal bluffs near Port Orford, southern Oregon, and the dwarfish and alpine *A. lanulosa alpicola* from the vicinity of the Timberline station in the Sierra Nevada.

The F_1 populations of these hybrids contain from 30 to 100 individuals per population, making it possible to study the variation within the population with respect to morphology and fertility. Within each F_1 population the variations in size and other characters bridge the gap between the parental populations, reflecting a high degree of heterozygosity within the parental plants. Nevertheless, if all characters are considered collectively, all the F_1 individuals are essentially intermediate between the parental forms. Within each F_1 population the fertility also differs from plant to plant. In open-pollinated plants the fertility varies from plants which set no seeds through the fertility range found

in the parental populations to plants that seed more heavily than the parental types. On the tetraploid level, therefore, the genetic barriers to interbreeding are not so distinct as in the diploids.

Second-generation hybrid populations derived from selected individuals of these F_1's have produced excellent material for analysis of the genetic differences between extreme races at this level. Although the observations on these tetraploid F_2 populations are not yet complete, certain facts are apparent. These are: (1) that the heterogeneity in the F_1 is reflected in differences between the F_2 populations derived from the same hybrid; (2) that transgressive segregations occur; and (3) that hybrid vigor is obvious.

Among the parental forms, only the coastal bluff form from Port Orford is moderately well adapted at Stanford, whereas both the tall marsh form from Suisun Bay and the alpine from Timberline suffer severely from heat and drought in the summer. In all the second-generation hybrid populations, most of the plants are as strong as or stronger than the parental races, and a considerable number exceed the F_1 hybrids in vigor.

On the hexaploid level the barriers to gene interchange are slight. The hybrids, which have been discussed in detail (Year Book No. 51, 1951–1952, pp. 122–124), show essentially the same characteristics as the tetraploid hybrids mentioned above. A vast array of segregation in the F_2 is found, with recombination types which exceed the parental variation. The hybrids are also distinctly vigorous in both the first and second generations.

One of the hexaploid hybrids, a cross between a dwarfish North Pacific alpine race from Kiska Island in the Aleutians and a giant race from the subtropical San Joaquin Valley in California, shows a remarkable hybrid vigor at Mather. Ten individuals of each parental race, the F_1 plants, and 300 F_2 plants were cloned and planted at the Stanford, Mather, and Timberline stations in 1952.

At Stanford this hybrid is vigorous in the F_1 and especially in the F_2 generation, None of the F_2 plants, however, exceed the San Joaquin Valley race, which there is extremely strong.

At Mather, on the other hand, both the parental races are near their survival limit, but appear to be eliminated for different reasons. The San Joaquin Valley race thrives on the summer heat but is killed during the winter, whereas the Kiska race suffers during the hot summer but survives the winters. The F_1 survives both winter and summer with excellent vigor, as do more than 90 per cent of the 300 F_2 plants. Moreover, most of the F_2 plants are highly vigorous. Not only do they surpass both parents, but many are more vigorous than the F_1 plants.

At Timberline this particular experiment was delayed by severe rodent damage during two winters. In a third planting in 1954, the plants were protected by wire screening that prevented further damage. Under this protection many of the F_2 plants have now survived the first winter at Timberline.

It is obvious that the expression of hybrid vigor that has been observed in the F_2 of the hexaploid hybrid at Mather and in the F_2 of the tetraploids at Stanford is contingent upon a recombination of the heredities of the ecologically contrasting parental races. The expression of vigor in each instance is dependent on the conditions imposed by the different environments. At both the hexaploid and the tetraploid levels, the heredities of the parental races may supplement each other in producing multitudes of F_2 forms that are extremely vigorous where one or both parents may fail.

PALEOBOTANY

Ralph W. Chaney

In spite of continued efforts for several past decades, as described in preceding annual reports, the search for living forests which correspond closely to those of the Tertiary period has been only partly successful. Such outstanding cases as the resemblance of the swamp cypress (*Taxodium*) forest of the southeastern United States to the Miocene Mascall flora of the John Day Basin, and the occurrence of the Chinese redwood (*Metasequoia*) in a forest containing many members of the Oligocene Bridge Creek flora, have been previously reported and provide reliable indications regarding Middle Tertiary environments. But even in these fossil floras, there are abundant members which have not been found in corresponding living forests. One of the most difficult of such discrepancies to explain has been the abundance of large evergreen oaks in the fossil record, and their lack of representation in living forests previously studied. A start was made in the solution of this problem in Japan in 1953. Current studies on Izu Peninsula in central Honshu, and in the mountains of Kyushu, are indicating the presence of several evergreen oaks, notably *Quercus stenophylla,* in forests which contain many other genera common in Middle Tertiary floras. These oaks range up from the almost subtropical lowlands into the deciduous forest which characterizes elevations above 1600 feet. The common Tertiary genus *Metasequoia* is not a member of this forest, for it became extinct in Japan some ten million years ago. But such broad-leafed deciduous genera as maple (*Acer*), alder (*Alnus*), birch (*Betula*), hornbeam (*Carpinus*), katsura (*Cercidiphyllum*), beech (*Fagus*), basswood (*Tilia*), and keyaki (*Zelkova*) share membership in both the modern and the Tertiary forests. Such conifers as fir (*Abies*) and pine (*Pinus*) are common associates of the past and present. The modern environment is extremely humid, with 120 inches or more of precipitation annually; temperature is mild, and of the sort we consider warm temperate in North America. An indicated summer-wet climate with little frost is in marked contrast with the present semiarid aspect of eastern Oregon, and the temperature range of today is much wider. Similar changes are noted elsewhere among Tertiary floras in the western hemisphere, and provide evidence of major alterations in atmospheric and ocean circulation, and perhaps of variations or cycles in solar activity. It seems clear that Middle Tertiary climate was warmer and more humid than has been suggested in earlier reports, but the degree of difference is yet to be determined.

Several basic conclusions regarding earth history may be derived from such modern vegetation studies when direct comparisons are made with the fossil record on both sides of the Pacific. Climatic zoning primarily controlled by latitude, and similar to that of today, has been fully demonstrated in the Eocene record of North America, where temperate forests have been recorded from Alaska, and warm-temperate to subtropical forests have been extensively studied in Oregon and California for several decades past; a notable difference is that climatic zones were some twenty degrees of latitude farther north in Eocene time than they are at present. A corresponding sequence of zones based on Eocene vegetation has been much less apparent in northeastern Asia, where all the known fossil floras have shown a temperate aspect. Current field work on the island of Kyushu has yielded a small but highly significant collection of Eocene plants including laurels, oaks, and other broad-leafed evergreens. Preliminary study seems to indicate that there was a subtropical forest in southern Japan during the Eocene epoch which had much the same aspect as that known from California and

Oregon. This evidence of similar zoning on opposite sides of the Pacific is of great theoretical interest, for it seems obvious that if the earth has maintained its present axis of rotation since Eocene time, the same general type of climate must have characterized both Asia and North America at corresponding latitudes at any one time.

A second conclusion based on the past season's work in Japan is that the climatic trend in Asia during the seventy million years of the Tertiary period has followed the same general sequence as in North America—from warm and humid toward the present temperate environment. Again, such a trend must have involved both continents if the North Pole has held its present position during later geologic time. But it should be emphasized that changes in climate have been much less pronounced in northeastern Asia than in western North America. There is even a suggestion of a swing toward much warmer and more humid climate in some of the living forests of Japan. Just how this localized moderating factor has operated is not well understood. But the resulting conservatism of modern vegetation in Asia has long been noted, and makes this continent a storehouse of information regarding the forests of the past. Here *Metasequoia, Zelkova, Cercidiphyllum,* and many other trees provide the only reliable evidence now available regarding ancient forest environments, and with the evergreen oaks help to reconstruct the terrain that characterized much of the northern hemisphere during past ages when these trees were widely distributed.

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DEPARTMENT OF EMBRYOLOGY

Baltimore, Maryland

GEORGE W. CORNER, *Director*

During the year 1954–1955 the work of the Department of Embryology has proceeded actively along lines set forth in recent Year Books. The research program at the home laboratory will be summarized below. More perhaps than in any previous year, members of the Department went far afield in pursuit of opportunities for research and for consultation with distant colleagues.

In January 1955 Dr. Robert K. Burns went, as in several past years, to the Conservation Reserve of the University of Florida, to collect material for his experimental studies on the opossum. The Department of Zoology of the University of Florida at Gainesville, unexpectedly lacking a leader for its course in mammalian embryology, requested the services of Dr. Burns. In view of the generous co-operation afforded by the University of Florida, the Director recommended to Dr. Bush that this request should be granted. As visiting professor Dr. Burns therefore extended his stay until June.

Dr. S. R. M. Reynolds was invited to spend two months in South America, during March, April, and May 1955, as guest professor at the University of Recife, Brazil, and at the University of Montevideo, Uruguay. At both these institutions he lectured and participated in the organization and conduct of research programs in the physiology of reproduction.

Dr. Arpad I. Csapo, who was appointed to a Guggenheim fellowship in the spring of 1954, left in June for Europe. He visited laboratories in Britain and the northern Continental countries, and gave numerous lectures and informal conferences. In several places he took part in research which was extemporized with the collaboration of local investigators who became interested in his problems concerning uterine muscle.

Dr. Gilbert S. Greenwald joined the Department in September 1954 on a fellowship of the National Institutes of Health. His work during the year on endocrinological factors in early embryonic life is summarized below under "Research in Progress."

Dr. William M. Paul, Fellow of the R. Samuel McLaughlin Foundation of Toronto, concluded his work with Dr. Reynolds and in January 1955 returned to his hospital appointment in Toronto.

On April 15, 1955, Dr. Mavis Joan Middlebrook joined the Department of Embryology, under appointment as a Carnegie Institution Fellow, to assist Dr. Arpad Csapo at Woods Hole.

Dr. Chester H. Heuser, Research Associate, again returned to the laboratory for two months in the summer of 1954. Several other workers who have unfinished projects involving the use of the collection of human embryos visited the Department briefly on one or more occasions during the year. These included Dr. Roy E. Crowder, Captain, Medical Corps, U. S. Navy; Dr. E. Carl Sensenig, University of Alabama; and Dr. Perry W. Gilbert, Cornell University, Ithaca, New York.

Dr. Benjamin C. Moffett, Jr., Assistant Professor of Anatomy, Medical College of Alabama, Birmingham, received a grant from the fellowship fund of the Carnegie Institution of Washington, which enabled him to spend the month of July 1954 at the laboratory. His investigations of the development of the temporomandibular joint, begun during this visit, are mentioned below under "Research in Progress."

A group of workers interested in the development of the joints of the human hand and foot spent a month, March 4 to April 4, 1955, at the laboratory making use of serially sectioned embryos and fetuses. These were Dr. Ernest D. Gardner, Pro-

fessor of Anatomy at Wayne University College of Medicine, Detroit; Dr. Ronan O'Rahilly, Assistant Professor of Anatomy at Wayne University; and Dr. Donald J. Gray, Professor of Anatomy, Stanford University School of Medicine.

Dr. Daniel Stowens, Major, Medical Corps, U. S. Army, attached to the Armed Forces Institute of Pathology, Washington, D. C., visited the laboratory at intervals during the year, using the collection of sectioned embryos to study the embryology of the nose (including Jacobson's organ) and maxilla in relation to the origin of certain maxillary tumors in infants.

Dr. Joseph Winsten, of the National Cancer Institute, temporarily attached to the Department of Surgery, Johns Hopkins Hospital, made use of the Department's facilities to study the form, topography, and anatomical relations of the parotid gland in human embryos and fetuses, in reference to the surgical anatomy of the parotid.

Dr. Tanomrudee Pumipak, Instructor in Anatomy, Siriraj Medical School, Bangkok, Thailand (introduced by the Foreign Operations Division, U. S. Department of Health, Education, and Welfare), visited the Department August 1–31, 1954, to study early embryos and observe technical methods.

Co-operative service. Dr. Corner continued during the year to serve as Chairman of the International Committee on Anatomical Nomenclature, which completed revision of the Basel *Nomina Anatomica* for submission to the Sixth International Congress of Anatomy at Paris, July 1955.

Dr. Elizabeth M. Ramsey continued her participation as consultant in the study of causes of fetal death in progress at the Columbia-Presbyterian Medical Center, New York City.

Recognition. Dr. Robert K. Burns was elected a member of the National Academy of Sciences, April 1955. He has been appointed to a Guggenheim fellowship tenable beginning in July 1955, and will spend about six months at the University of Paris, where he has been named Exchange Professor.

The award of a Guggenheim fellowship to Dr. Arpad I. Csapo, for one year tenable in 1954–1955, has been mentioned above.

The Director was in May 1955 elected Foreign Member of the Royal Society of London, and was formally received at a meeting at Burlington House, June 30, 1955. He was also elected Honorary Fellow of the Royal College of Obstetricians and Gynecologists of Great Britain. On May 31, 1955 the degree LL.D. was conferred on Dr. Corner by Tulane University.

At the conclusion of Dr. Reynolds' visit to the University of Recife, the Faculty of Medicine held a special convocation ("Homenaje") in his honor.

James Francis Didusch, 1890–1955

James Didusch, who was the illustrator of the Department of Embryology from the time of its organization in 1913, died on March 16, 1955. During all these years, with one brief interlude, he illustrated the researches of members and associates of the Department with a remarkable combination of accuracy and beauty. He acquired a sound knowledge of human development, and himself became a contributor to the precision and clarity of work published from the Department and sometimes an anonymous colleague in the research. Although from time to time he also illustrated clinical books and articles, his real lifework is in the successive volumes of the Carnegie Contributions to Embryology. Among hundreds of drawings, it is difficult to choose those which best illustrate his beautiful style. Notable among his early work are the plates for L. H. Weed's monograph on the cerebrospinal spaces (vol. 5) and for Florence Sabin's article on the primitive blood vessels (vol. 6). Later on, he drew a series of pictures of important human embryos which have become classics of embryological art and are widely copied in the text-

books, the finest of all perhaps being the lateral view of a 10-somite embryo, Carnegie 5074, in volume 20. A special talent for clear and simple diagrammatic representation without loss of the similitude of animal tissues is shown by a page of diagrams illustrating the placentation of the rhesus monkey (vol. 27, p. 9). Even in the last volume published in his lifetime (vol. 35), the many drawings made when his health was already failing show his characteristically firm touch in line drawing and his refined half-tone style. Mr. Didusch was widely recognized abroad as well as in the United States as one of the greatest scientific artists of his time.

THE WORK OF THE DEPARTMENT OF EMBRYOLOGY, 1913–1955

When the Carnegie Institution of Washington made, in 1913, the original grant which led to the organization of the Department of Embryology, it did so in response to a forceful statement by Franklin P. Mall about the possibility of making great advances in the knowledge of human development if a concerted, well-supported attack could be organized. Mall's "Plea for an Institute of Human Embryology," published in the *Journal of the American Medical Association* in 1913, is thus the scientific charter of the Department of Embryology.

In that document Mall wrote, "With a very large collection, a competent staff and the very best material equipment the institute would naturally take up problems which bear on anatomy, physical anthropology, comparative embryology, physiology of gestation, pathology and teratology." He listed certain large questions which at once presented themselves: (1) Curve of growth. (2) Anatomy of various stages; modeling, dissection, etc. of internal structure. (3) Morphology of the brain. (4) Histogenesis: the differentiation of the various tissues. (5) The causes of spontaneous abortion. (6) Study of monsters. (7) Study of moles (proliferative malformations of the placenta and membranes). (8) Comparative and experimental embryology.

Questions like these were, of course, merely some of those which Mall considered to represent attainable aspects of the whole task of understanding human reproduction. They formed part of a systematic program, in which, first, the ordinary development of the human embryo must be observed. The norm of growth and of external form must be established. Embryos must be arranged in stages. The methods of physical anthropology should be applied to the embryo and fetus, to understand the beginning of racial differences and to explain marked anatomic variations. Abnormal and pathologic embryos should be classified, with a careful study of the uterus and Fallopian tubes in which they were found. The internal pathology of human embryos was to be investigated with care. Mall went on to say that the program might seem to emphasize unduly the making of a collection, but that was not the intention, for he considered that the chief function of an institute of human embryology should be the formulation and solution of problems.

Let us look back over the forty-two years that have elapsed since Mall drew up his program, and see what has been done toward its accomplishment. Mall himself lived only long enough to get the enterprise started, and his plans had to be developed by his successor, George L. Streeter. The Department of Embryology today possesses the "very large collection" of human embryos Mall envisaged; this is by far the largest in the world, and is well prepared, safely housed, and kept usable by good records and ample indexes. Thirty-five volumes of the Contributions to Embryology have been published, and also numerous articles in other journals.

1. The first problem on Mall's list, that of the norm of growth, may be said to

have been solved. We now know the external appearance and dimensions of the human embryo and fetus day by day from the two-cell stage to birth. The time schedule of development has been worked out with a fair degree of certainty, so that the age of an embryo can be determined from its external appearance with an error of plus or minus one day, in the first seven weeks, and to the correct week in later stages. The records and data on this time schedule include a superb collection of photographs and models, a descriptive catalogue (*Developmental Horizons in Human Embryos,* begun by Streeter) which when completed will cover the whole embryonic period, and Streeter's tables (in vol. 11 of Contributions to Embryology), which furnish norms of growth in weight and length of the body, and various other useful dimensions throughout gestation.

2. The "anatomy of various stages," as Mall put it, is of course the chief concern of formal embryology. The special accomplishment of the Carnegie laboratory has been the accurate reconstruction in three-dimensional models of the internal structures throughout the embryonic period, more completely than was possible anywhere else. Descriptive texts have been written on many important special topics, including for example the muscles; the heart, lungs, and lymphatic system; the brain and cerebrospinal spaces; the diaphragm, adrenal gland, ovary, uterus, kidney, and urinogenital ducts. The list is too long for full citation here. Similar work has of course been done in many other laboratories, but the embryologists of the world look to the Carnegie laboratory as the headquarters of this kind of research, and to its material as the standard of comparison. A measure of the contribution to science thus made is given by the fact that in some current textbooks of human embryology 25 per cent or more of the illustrative material is taken from the Contributions to Embryology.

Mall's very original idea of applying the techniques of physical anthropology to the embryo and fetus has been fruitfully applied in working out the curve of growth and the changes of bodily proportions during development (mentioned above), and also in studies on racial differences, e.g. between the white and Negro races, as they appear in prenatal life.

3. The morphology of the developing human brain has been worked out in great detail. Although this subject has not occupied the laboratory in recent years, much of our current knowledge still rests on work done here.

4. The histogenesis of various organs and tissues has been studied in a somewhat less systematic fashion than the previously mentioned subjects. The field is vast, and the choice of particular organs for investigation has depended on current interests and on special opportunities presented by favorable material. It may be said that the Carnegie laboratory has been one of a number of productive centers of research, and that with regard to certain organs and tissues valuable contributions have been made as called for by Mall's program.

5, 6, 7. The Carnegie Collection includes a large amount of abnormal embryonic material representing abortive, retarded, and monstrous development, much of which has been classified and described. A considerable body of information has been organized concerning the types of embryonic and fetal abnormality and the periods of gestation at which they occur. The causes of such anomalies are, however, very complex, and to understand them we need information from other fields of biology not extensively cultivated here, especially general experimental embryology and genetics. It may fairly be said that the Carnegie laboratory has contributed its share to this joint undertaking by collating the available information given by human material, and that the constant interest of senior members of the staff and their published cogitations on this subject have been valuable.

8. Because the original emphasis of Mall and Streeter was on human embry-

ology, experimental embryology did not at first receive much attention in the Department. Experimental studies on embryonic differentiation have been well supported at the marine biological laboratories and in various university departments of biology, and such work could be appropriately left to those institutions.

Likewise, to go deeply into comparative embryology would have required a serious diversion of resources. Many valuable studies of early mammalian development were, however, made on the rat, mouse, guinea pig, rabbit, and domestic pig. Above all, the Department has taken for its own field the embryology of the non-human primates. The expensive organization required to breed monkeys and to obtain simian embryos collected in the tropics justifies this effort in an endowed research laboratory. The Department now possesses and continues to exploit a rich collection of primate embryos.

In summary, most of the special lines of research suggested by Mall have been effectively pursued. It was also inevitable that opportunities would occur to develop lines of study which he could not have foreseen. Notable work of this kind is that on the cultivation of tissues in vitro which grew out of the early studies on morphogenesis, and which made the Department from 1915 to 1940 one of the world's chief centers of experimental cytology and tissue-culture techniques. Another side line that assumed major importance was the analysis of the reproductive cycle, including especially the phenomenon of menstruation and of cyclic changes in the uterus and ovaries. This work grew out of the effort to produce primate embryos of known age by breeding monkeys in the laboratory, and out of the need to date the corpus luteum of pregnancy. It yielded a great contribution to the understanding of the human cycle and has had much influence on practical endocrinology, gynecology, and obstetrics.

Much of the achievement described in the foregoing paragraphs was attained during the long incumbency of the second director, George L. Streeter. When the present director (whose immediate services to the Carnegie Institution of Washington will end about the time of publication of this report) assumed charge of the Department, it was apparent that a gradual shift of emphasis was necessary. Studies of embryonic form and the sequence of internal change had, as we have seen, been brilliantly and effectively pursued. The next need was for an increased effort to understand embryonic development in terms of physiology, biophysics, and biochemistry. The Department had under Mall and Streeter by no means resisted the experimental approach; the work on tissue culture and that on the reproductive cycle, mentioned above, and also much work on the morphogenesis of blood vessels and other studies using living animal material, gives evidence that morphology was never the sole preoccupation. The great strength of the Department has always been the association and interplay of morphological and physiological thinking. Morphology could not, however, effectively remain, as in the past, the major interest of the laboratory. The third director's task has been (and that of his successor will be) to hold fast to the solid achievement in morphology, to maintain the great collection in working condition, and to keep it usefully employed, while at the same time directing attention to the physiological, chemical, and physical problems of embryology and of mammalian reproduction. During the period 1940–1955, in pursuit of these aims, an important study of embryonic differentiation of the urinogenital tract, by experimental methods, has been carried on. The physiology of the uterus as an organ, and the biochemistry of uterine muscle, have been investigated. The fetal circulation is being studied by rapid X-ray cinematography. The placenta has been deeply explored as to structure and function. An investigation of the almost totally obscure physicochemical phenomena of embryonic implantation has been begun.

The endocrinology of the ovary and uterus has been studied. Experimental investigations have been made on the biochemistry of the male reproductive tract.

The collection of human embryos continues to be actively used. Analysis and publication of the earliest stages of human development has been continued and almost completed. Although the main outlines of human development have thus been worked out, there remains great need of detailed descriptions of the development of individual organs and regions of the human body. For example, recent advances in the surgery of the heart and great vessels has called for better knowledge of the embryology of these structures. Such special demands will doubtless present themselves for a long time to come. A series of human embryos skillfully prepared to demonstrate nerve tissues would be very useful. A further possibility for diversification of the collection lies in the rapid development of microchemical techniques for the localization of special substances in the tissues.

All those workers who have so faithfully and enthusiastically devoted themselves to this program will unanimously testify that the great advantage, for them, of working in the Department of Embryology has been the constant association, within one group, of competence in both morphological and physiological study. The concept that an embryo is a living, functioning organism was present in Mall's mind as in that of Streeter. With the progress of biochemistry and biophysics it begins to be possible to implement that concept by simultaneous application of sound morphological knowledge and the methods of experimental physiology and biochemistry.

Under the fourth director of the Department of Embryology, it may be confidently predicted, there will be much greater progress toward understanding the development of the embryo in terms of physical chemistry, e.g. enzyme reactions and the chemical upbuilding of tissues. With equal confidence it can be foreseen that each advance in our knowledge of the molecular reactions in cells and tissues will in turn throw light on the mysterious way in which the cells interact to form the organized structure of the embryo and mold that structure to the exact pattern of its own species, even of a particular race or family line. Thus the biochemistry of the embryo will call for constant review of its morphology; and in turn the marvels of organized form and structure will go on posing new problems for the student of molecular constitution. The Department of Embryology will of necessity have to consider, as far as its means and staff can reach, the full gamut of life structure from the electron to the whole organism.

RESEARCH IN PROGRESS

Histogenesis, Organogenesis, Pathology

Neural crest. The previous work of Dr. G. W. Bartelmez on the origin of neural-crest cells from the optic cup in human embryos is cited below under "Published Research." During the year of the present report Dr. Bartelmez has continued examination of this question in embryos of the rhesus monkey, the capuchin monkey, the lemur *Microcebus,* and the rat. Material from all these forms was available in the Departmental collections. A report is almost ready for publication.

Temporomandibular joint. Dr. Benjamin C. Moffett, of the University of Alabama School of Medicine, began in the summer of 1954 a study of the development of the temporomandibular joint in human embryos. This joint, highly important because of its role in speech and mastication, is very peculiar in certain aspects of its development. Fetal material, with which to supplement the embryonic stages studied by Dr. Moffett in the Carnegie Collection, was supplied for subsequent preparation at Birmingham. A

manuscript now completed for volume 36 of the Contributions to Embryology provides an account, much more detailed than has previously been available, of the timing and sequence of events in the formation of this joint, the interception and inclusion of part of the tendon of the external pterygoid muscle to form the articular disk, and the development of the joint capsule.

The fetal lung. Dr. Reynolds has completed an investigation of the blood vessels of the fetal lung, seeking to understand the anatomical arrangements by which the vascular bed of the lung can be suddenly expanded when respiration begins at the time of birth. His previously reported studies of the pulmonary blood flow by X-ray cinematography have emphasized the massive changes in capacity and rate of flow which occur as the fetal lung expands. The histological studies have revealed a special pattern of the arterial capillaries accompanying the alveolar ducts. In the unexpanded lung these vessels are preformed to ample size but are closely coiled. Their capillary branches to the undistended alveoli are consequently closely packed. The system is therefore ready for immediate functional expansion. The congestion of these coiled blood-filled vessels offers resistance to the blood flow in the fetal lung. Thus in fetal life the blood is directed through the ductus arteriosus on the way to the placenta. When respiration begins, the resistance to the blood flow through the lung is diminished, and the changes in blood volume and flow through the lung, mentioned above, are set up.

Development of the cranial veins. Mrs. Dorcas H. Padget, former Fellow, completed during the year the manuscripts of two fully illustrated articles on the development of the venous system of the head in human embryos, thus bringing to conclusion a long and comprehensive investigation for which support was provided by the Life Insurance Research Foundation and later directly by the Carnegie Institution of Washington.

Pathology of the embryo and fetus. Dr. Elizabeth M. Ramsey examined during the year 98 specimens sent by 33 institutions and private physicians from 15 cities in 10 states and Alaska. Reports were given to all the senders. Thirty-seven of these specimens had sufficient research or museum value to justify permanent preservation.

Dr. G. W. Bartelmez examined a number of sectioned human embryos and fetuses in the Carnegie Collection which were obtained by abortion because of a history of severe mental defects in the parents, or of German measles in the mother at a critical stage of pregnancy. In none of the specimens have any lesions been found in the central nervous system.

Endometrium, Placenta

Endometrial blood vessels and menstruation. Dr. G. W. Bartelmez continued his study of the uterine lining, and especially of its blood vessels, in relation to the phenomenon of menstruation. He completed a paper on the ischemic phase of the cycle in the rhesus monkey and man, in which he gives special attention to the question of arteriovenous anastomoses of the endometrial vessels. Such communications between arteries and veins have been described and used in the construction of hypothetical explanations of premenstrual ischemia. Dr. Bartelmez finds no evidence of their existence.

A study of the vascular changes during the menstrual cycle in the rhesus monkey, with detailed diagrams of the changing pattern of the coiled arteries, is nearly ready. Dr. Bartelmez also has under way a report on the histology of the blood vessels of the human and macaque endometrium with special reference to the phases of menstrual breakdown and repair.

The placenta. Dr. Elizabeth M. Ramsey is continuing to accumulate material for study of the human placenta. Preliminary study of the sections reveals mounting evidence for the essential similarity of placental arrangements in macaque and hu-

man. The nature of the circumstances occasioning such differences as do exist is also becoming clear; for example, superficial implantation in the monkey, with the formation of an epithelial plaque at the site of attachment, as against interstitial implantation and true decidua formation in the human. It may be hoped that the extensive material being assembled and studied will justify formulation of certain generalizations to be used as a sort of conversion factor for application of the "monkey yardstick" to the human placenta, much as the Heuser-Streeter yardstick of monkey embryos is used, in the study of young human embryos, to estimate the age of an uncertainly dated human embryo by comparison with the closely dated monkeys.

The contribution of beautifully prepared specimens by colleagues in other institutions is again acknowledged. Dr. Irwin H. Kaiser of the University of Minnesota, Dr. Clark Gillespie of the University of Arkansas, Drs. I. A. Siegel and Tobias Weinberg at Sinai Hospital, Baltimore, and the staff of the Department of Gynecology at Johns Hopkins Hospital have all sent valuable material.

The Blastocyst: Transportation, Attachment, Maintenance

Transport and spacing of rabbit embryos in the uterus. It was reported last year that Dr. Bent G. Böving had, by statistical procedures, found that rabbit blastocysts are approximately evenly spaced in the uterus at the time of implantation. This year similar procedures have been applied to specimens representing each of the four preceding days, that is to say, from the entry of the blastocysts into the uterus to the time of implantation. The study is intended to provide not only a description of the normal rate of transport and spacing, but also a standard with statistically defined limits with which one may compare the location of blastocysts in future experiments on the mechanisms regulating transport of the blastocysts. The recent work has added the observation of blastocyst diameter to notations of their number, their position, the length of the uterus, and the age of pregnancy. It is hoped that analysis of this information will help to determine whether the transport rate is closely controlled by obvious mechanical factors or by more complex biological and chemical factors requiring further exploration.

Mechanics and chemistry of attachment of the embryo. The first cellular attachment of the embryo to the uterus is an adhesion and penetration by trophoblast, which Dr. Böving has previously found to involve specifically those cells in the uterine epithelial lining that have a blood vessel at their base. When silver nitrate solution is perfused through the blood vessels of the uterus at this stage of pregnancy or just before, sharply localized precipitates of silver compounds are found in just such uterine cells. A day later, when the trophoblastic invasions have spread out, the silver precipitates are also more widely spread. Moreover, the intercellular membranes of the uterine epithelium were present when invasions and chemical transfer were localized, but they had disappeared or were disintegrating when invasions and chemical transfer were spreading. It is concluded that the intercellular membranes determine the pathway of a chemical transfer between blastocyst and maternal circulation and thereby determine both the location and the form of trophoblast invasion.

The nature of this chemical transfer which apparently promotes trophoblast adhesion and invasion has been studied. The precipitates themselves are believed to be a product formed by silver ions from the perfusing fluid and either carbonate or bicarbonate ions from the blastocyst, perhaps facilitated by local alkalinity. This interpretation was supported by a crude imitation of the precipitates, produced when ordinary salt solution saturated with cal-

cium carbonate and carbon dioxide was substituted for a blastocyst in a pregnant rabbit or in a previously ovariectomized rabbit treated with progesterone. The imitation failed in a nonpregnant animal and an ovariectomized one treated with estrogen, and in the controls, in which no saline-carbonate solution was injected. This finding agrees with a working hypothesis that the transfer revealed by the silver perfusion, which presumably promotes trophoblast adhesion and invasion, is controlled by progesterone through augmentation of uterine carbonic anhydrase (an enzyme which speeds the interconversion of carbon dioxide and carbonate ion). Such a relation between progesterone and carbonic anhydrase, shown to exist in the rabbit by Dr. C. Lutwak-Mann, of Cambridge University, England, provides a very plausible link in the chain of events.

In order to analyze the earliest phase of attachment, i.e. the first adhesion of the blastocysts, Dr. Böving with the advice and help of Mr. O. O. Heard is developing a device for measuring the adhesiveness of the blastocyst in various solutions.

Effect of estrogen on early embryos. Dr. Gilbert S. Greenwald has been investigating the mechanism by which the ovarian hormone estrogen destroys early embryos of laboratory animals when injected into the mother during the first weeks of pregnancy. That such injections terminate pregnancy has been noted by several investigators; how the lethal action is exerted has not been fully understood. The research in progress has centered primarily on injections during the first seven days of gestation. Dr. Greenwald plans to extend the observations to the later stages of pregnancy during the coming year. He finds, in confirmation of results of preliminary experiments by Dr. Csapo, that estradiol in doses as small as 5 gamma daily for 3 days, commencing on the second day after fertilization, produces death of the embryos while they are in the oviducts. Direct injection of estradiol into the lumen of the oviduct is lethal in even smaller doses. Such treatment, which does not disturb the progestational reaction in the uterus, does interfere with the production of a decidual reaction; but this cannot be a factor in death of the embryo during the first few days, before the blastocyst enters the uterus. A chemical action on the blastocyst by way of the tubal epithelium must be postulated.

Death of the embryos caused by injection of estrogen on the fourth day of pregnancy or later is produced by a different mechanism, involving the transport and spacing of the embryos in the uterus.

Other work in progress by Dr. Greenwald includes a comparison of delayed implantation with normal implantation mechanisms and a histological study of the ovarian cycle of the muskrat.

Reproductive Tract: Differentiation and Maintenance

Sex differentiation. Dr. R. K. Burns, as mentioned above, again collected opossums in Florida in February–March 1955, and conducted experiments on pouch young in the field. At the home laboratory his experimental material from the previous year was prepared for microscopic study, which fully confirmed the striking result mentioned in the last report, that embryonic testes had been so far modified by injections of estrogen that ovocytes had developed in an ovary-like cortex produced from what was originally testis tissue. Experiments of the same type were conducted this year, but with smaller doses, experience having shown that very small quantities of estrogen are tolerated longer by the pouch young. Thus Dr. Burns hopes to carry his experimental animals long enough to see how long the effects of the estrogen persist, and how extensive they will be when the hormone has acted as long as possible.

Utilizing pouch young of animals that were trapped too late for the experiments just mentioned, Dr. Burns has made experiments to define the period of gestation

during which inhibition of the development of the prostate of male pouch young can be produced by a single injection of estrogen. The reproductive tracts of these animals are yet to be sectioned.

Dr. and Mrs. Burns continued to collect data on the duration of the breeding season of the opossum in Florida, the litter size, and the number of young in mothers of varying age, weight, and maturity.

Production of androgen by the adrenal gland. Experiments of Dr. David W. Bishop on transplantation of the accessory male reproductive organs of the rat, tentatively summarized in Year Book No. 53, have been completed and are being prepared for publication. The essential findings are that androgen is produced by the adrenal glands of male and female castrates in sufficient amounts to sustain the secretory activity of seminal vesicular and prostatic subcutaneous grafts, that the female adrenal seems to have a greater androgenic effect than does that of the male, and that this androgenic activity of the female adrenal may, in some circumstances, overcome the inhibiting estrogenic effect of the ovary.

Physiology of the Fetus

The amniotic fluid. An experimental study of the pathways of exchange of fluid between the amniotic cavity and its surroundings was made by Dr. William M. Paul and Dr. S. R. M. Reynolds with the collaboration of Dr. Francis P. Chinard and Dr. Theodore Enns, of the Department of Medicine, Johns Hopkins University. Heavy water (deuterium and tritium) provided the tracer substances. Basing their study on known characteristics of the fetal membranes and their blood supply in the rabbit, the investigators were able to apply methods by which the fetal circulation through the membranes could be eliminated without injury to the fetus, leaving only the maternal vessels as source of blood supply to the membranes. The measurements of water exchange indicate that about half the exchange of water in and out of the amniotic cavity occurs across the placenta by way of the fetus, and about half by way of the membranes directly from the maternal circulation.

Fetal circulation. Dr. Reynolds and Dr. Paul carried out a series of experiments on pregnant sheep designed to measure and analyze the effect of intrauterine pressure, applied to the fetus, on the fetal blood pressure and heart rate. Obstetricians are aware that the heart rate of the late human fetus decreases during strong contractions of the uterus. The physiological cause of this phenomenon is, however, unknown. In the experiments of Reynolds and Paul, pressure was applied by placing weights on the uterus, by manually compressing that organ, or by causing it to contract by an injection of the pituitary hormone Pitocin. Under such circumstances the fetal heart rate is slowed by inhibition through the vagus nerve. Changes in fetal blood pressure occur, but are characterized by unexpected variations which doubtless point to regulatory processes within the fetus. Further experimental analysis indicates that the response to increased pressure within the uterus is the result of lowered oxygen supply to the fetal brain and consequent excitement of the vagal centers.

X-ray cinematography of the fetus. During the year progress was made, despite harassing delays, in the completion and installation of the apparatus for X-ray cinematography with which Dr. Reynolds plans to continue his investigation of the fetal circulation. An adequate power line has now been provided by the Johns Hopkins University, and the apparatus has been assembled, in spite of delay in the procurement of an essential timing device, to a point at which preliminary tests have been made and some noncinematographic roentgenography has been done in support of other work of the Department.

Physiology of Oviduct and Uterus

Oviduct. Dr. David W. Bishop has devoted much of his time during the year

to study of the physiology of the oviduct (Fallopian tube). An investigation of the tubal fluid of the rabbit oviduct, now nearing completion, indicates that it plays a significant role in the welfare of the blastocyst. The fluid is copiously secreted during and immediately after ovulation, but the rate of its accumulation in ligated tubes is depressed after castration and during late stages of pregnancy. Ligation of the oviduct at the uterotubal junction at about the fourth or fifth day after fertilization, at a time when the blastocysts have already passed into the uterus, can impair blastocyst growth. The theory that the normal growth of the blastocysts, immediately before implantation, may result simply from osmotic uptake of water from the surrounding fluid has, however, been tentatively ruled out, since both measurement of freezing-point depression and determination of sodium and potassium in the tubal fluid indicate an osmotic value close to, but a little above, that of blood serum. Preliminary determinations of the osmotic value of blastocyst fluid (Böving and Howard) indicate that this too is comparable to that of blood serum.

The tubal environment has been found to be aerobic, as indicated by oxygen-determination procedures involving both the methylene blue reduction method and a modification of the micro-Winkler technique. The presence of oxygen in the tubal fluid, approximately 6 to 9 parts per million, permits oxidative respiration both by the spermatozoa and by the fertilized eggs, as noted in Year Book No. 53. In the absence of a dependable source of sugar in the tubal fluid (spectrophotometric determinations have demonstrated that free sugar may be absent, or present in only very small amounts, in this environment), an oxygen-consuming state of metabolism is essential. The availability of the most likely oxidative substrate, phospholipid, is not yet established. The spermatozoa, however, very probably utilize their endogenous phospholipid reserves during their sojourn in the oviduct, a supposition with both practical and theoretical implications, since the depletion of this substrate will determine their survival, and their dependence on oxidative phospholipid respiration makes mammalian (rabbit) spermatozoa conform to the metabolic pattern of most invertebrate sperm.

Pain thresholds of the cervix uteri. Dr. Reynolds, Dr. Paul, and a physician from the Departments of Obstetrics and Gynecology of Johns Hopkins Hospital, Dr. Irving N. Cushner, have begun a study of the pain thresholds of the human cervix uteri, intended to provide information regarding the nature of dysmenorrheal pain and a basis for testing pain-reducing drugs. By means of a small elastic balloon introduced into the cervical canal, and attached to a syringe acting as a fluid pump to distend the balloon, thresholds of painful response to distention have been measured at various levels of the cervical canal, and at various times in the menstrual cycle. Clear differences are appearing between women who do and do not suffer from dysmenorrhea.

Physiology of the Myometrium

Dr. Arpad Csapo continued his investigations of the physiology of uterine muscle peripatetically during the year, i.e. by brief collaborative experiments at several laboratories abroad, July–September 1954; at the home laboratory January–March 1955; and at Woods Hole during the second phase of his Guggenheim fellowship, April–June 1955. The following lines of study have been pursued.

Uterine muscle strips taken from a pregnant rabbit, over a placental site and between two sites, respectively, differ in their behavior when made to contract in vitro. Muscle tissue which is near a placenta is more strongly dominated by progesterone than that which is farther away. This observation, which has been controlled by suitable variations of the experiments, points to local action of progesterone pro-

duced in the placenta upon the adjacent uterine muscle. The concept is evidently of very great significance with regard to the physiology of gestation and labor.

Another study concerns the threshold of excitability of the uterine muscle when stimulated electrically, and its relation to the potassium gradient, i.e. the ratio between the concentration of potassium within the muscle cell and that outside it. As the potassium gradient is decreased by reducing the proportion of potassium chloride in the salt solution in which a strip is suspended, the threshold is lowered and excitability increased. Oxytocic drugs act by decreasing the potassium gradient (depolarization of the cell). This relation obtains, however, only down to a critical membrane potential of about 50 mV, below which contracture sets in and excitability decreases. Under estrogen domination the membrane potential of muscle is well above this critical value. Its function can be improved by oxytocic drugs, because they lower the membrane potential. An overdose of an oxytocic drug, however, leads to contracture and decreases the tension produced by stimulation. Progesterone seems to depolarize the membrane permanently, bringing the membrane potential below the critical value. Oxytocic drugs are then ineffective and can only cause contracture. The muscle is thus in a state of "pregnancy reversal" like that first described by Sir Henry Dale and by Professor A. R. Cushny in 1907. A very puzzling problem of uterine physiology, of considerable clinical importance, seems now to be explainable.

Dr. Csapo has evolved a theoretical explanation of the spontaneous activity of smooth muscle, involving the action of an intrinsic recurrent stimulative chemical process in varying states of polarization of the muscle cells. This analysis is being prepared for publication, and further work is in progress on the kinetics of potassium depolarization.

Growing experience with the slowly contracting uterine muscle has enabled Dr. Csapo to attack a very important problem that has heretofore been studied only in skeletal muscle, and with great difficulty because of the extremely rapid contractions. This is the question as to when, in the contraction cycle, the bond energy of the high-energy phosphate fuel (adenosine triphosphate) is utilized. Experiments are now in progress with the assistance of Dr. Mavis Joan Middlebrook.

PUBLISHED RESEARCH

Early Primate Embryology

The earliest human embryos. Publication of volume 35 of Contributions to Embryology marks the closing of the last gap in our knowledge of the external form and general structure of the human embryo from the one-celled egg onward. In that volume Dr. Arthur T. Hertig, Dr. John Rock, Miss Eleanor C. Adams, and Dr. William J. Mulligan describe four normal and four abnormal human embryos from the second to the fifth day of development.

The long association of Dr. Hertig and Dr. Rock with the Department of Embryology has been the subject of comment in these annual reports for the past twenty years, and the fruits of their work, done in co-operation with Dr. C. H. Heuser and the technical staff of the Department, have been a notable feature of the Contributions to Embryology. Almost all that is known about the human embryo during the first two weeks of development has been learned from the Hertig-Rock series.

The normal embryos now described and illustrated in full include one of 2 cells (no. 8698), a 12-cell morula (no. 8904), a 58-cell blastula (no. 8794), and a 107-cell blastula (no. 8663). Those considered abnormal are morulas of 5 to 12 cells.

In comparison with similar stages of other mammals already described, these unique specimens present no great sur-

prises. It was to be expected that the human species would be found to resemble other mammals in the earliest days of development; but to those who have had the privilege of handling and studying these rare gems in the treasury of science, the mere fact that they are human, and that they do fit into the known picture of organic evolution and development, is a sufficient cause for wonder and exultation. The skill and persistence with which Dr. Hertig and Dr. Rock planned and achieved the collection of these embryos, and the perfection of Dr. Heuser's technique in sectioning them, are admired by biologists throughout the scientific world.

Something can be made out from the histories about the rate of transport of the human ovum. The 2-cell stage is thought to be about 36 hours old, calculating from the time of ovulation. It was recovered from the oviduct. The 12-cell morula is about 72 hours old; it was in the uterine cavity. At about 96 hours the 58-cell stage was found. The 107-cell blastocyst is about 108 hours old. To judge from the earliest implanted specimens in the Collection (nos. 8020 and 8225, each 7½ days old), this free blastocyst was not quite ready for attachment. The human embryo probably becomes attached about the sixth day, passing through the preimplantation stages a little more rapidly than that of the rhesus monkey, which becomes implanted about day 9.

Early development of the baboon. Following a visit to the Department of Embryology by Dr. Joseph Gillman in 1943–1944, a co-operative program was arranged with the Department of Anatomy of the University of the Witwatersrand, Johannesburg, for obtaining embryos of the baboon *Papio ursinus.* Financial support was provided for three years by the Carnegie Institution of Washington. By planned breeding, six embryos of accurately known age, from 12 to 34 days after ovulation, were obtained. Two of these were abnormal, a proportion which might have been expected from our knowledge of morbidity rates in other animals. The four which were normal constitute practically the entire material available for study of the early development of the baboon, only one other embryo of comparable age being known. Dr. Christine Gilbert, of Johannesburg, who had been largely responsible for securing these specimens, was given a fellowship of the Carnegie Institution of Washington for 1950–1951. In association with Dr. C. H. Heuser, who had sectioned the embryos and made preliminary studies of them, Dr. Gilbert spent her fellowship year preparing a fully illustrated description.

The series, though small, is well enough spaced (embryos of 12, 20, 30, and 34 days, with the two abnormal specimens of 22 days) to give a good idea of the timing of developmental events in the baboon. These follow a sequence comparable to that already known for man and the macaque. The intraembryonic mesoderm begins to proliferate about day 13. The axial notochord and primitive streak are laid down between days 12 and 20; the primordia of all the major organs and systems are fashioned between days 20 and 34. The baboon has a single placenta of the chorioallantoic type. A peculiar feature is the existence of large blood vessels in the amniotic mesoderm.

Dr. Gilbert and Dr. Heuser, impressed by the similarity of the development process in baboon, macaque, and man, in sequence and in timing, throughout the early embryonic period up to the end of the presomite stage, suggest the existence of a pattern of development which is peculiar to primates and which differs from the patterns encountered in other mammalian orders. If we are ultimately able to establish all the features of this developmental pattern in primates, then the interpretation of events in the embryogenesis of the baboon and macaque may become significant for understanding problems of early growth and differentiation in man.

Histogenesis and Organogenesis

Formation of neural-crest cells from the optic vesicle. The neural crest is a fundamental feature of vertebrate development, for all the way from the sharks to man this tissue arises from the neural folds and its cells migrate to the periphery of the body, giving rise to pigment cells in the mesenchyme. The existence of a neural crest in human embryos is well known, but it has remained for Dr. G. W. Bartelmez to discover the remarkable fact that the human optic cup also carries out with it, as it develops from the neural tube, cells which partake of the nature of neural crest. These cells begin to migrate, at the stage of 15–16 somites, into the sheath of mesenchyme around the primary optic vesicle. They lose their definitive characters after several divisions, but in a 25–26-somite embryo Dr. Bartelmez found more than a thousand sheath cells crowded between the optic vesicle and the surface ectoderm. The crest cells can still be recognized as such in embryos of lens-vesicle stages. Although they cannot be distinguished long thereafter, the tissue in which they lie on the surface of the secondary optic vesicle does not show cellular degeneration, and thus it is highly probable that the neural-crest cells become part of the uveal tunic. In amphibians and birds, uveal pigment has been shown to develop from neural-crest tissue. Dr. Bartelmez suggests that the optic neural crest of man has the same fate. This discovery and the deductions based on it not only would help to explain the development of pigment in the iris and the choroid coat of the eye, by correlating it with pigment formation by neural-crest derivatives elsewhere in the body, but may also provide clues as to the genesis of certain pigmented tumors of unexplained origin. Preliminary observations indicate that neural-crest cells are formed from the optic vesicles of other primates also, and of certain insectivores. A continuation of these comparative studies is mentioned above under "Research in Progress."

Development of the human diaphragm and pleural sacs. A long study of the development of the diaphragm by Dr. L. J. Wells, begun in 1947 when he was at the Department of Embryology as a Guggenheim Fellow on leave from the University of Minnesota, has finally reached completion and publication in the Contributions to Embryology. Work on this ambitious project was held back by the illness of the late J. F. Didusch, whose skilled graphic interpretation of Dr. Wells' notes and models was essential to the task because of complex problems of illustration that were involved.

It is an interesting fact that Dr. F. P. Mall, founder of the Department of Embryology, was deeply interested in this subject, which is one of the most difficult in the whole field of morphology. He published in 1901 a well-known paper which however suffered from a lack of good specimens. Dr. Wells was able to examine the same embryos which Mall had studied, and to supplement them with numerous more recent and mostly better-preserved embryos. He also made numerous dissections of human fetuses from the Department's material. From these preparations and from models made by Mrs. Mary McCarthy Cope, Mr. Didusch produced thirty drawings. This was, incidentally, the last large undertaking of his career.

The resulting monograph is necessarily prepared for specialists, and even a summary must seem technical. Dr. Wells concludes that the primitive diaphragm may be regarded as a single structure with six blended regional subdivisions, the transverse septal (gastrohepatic, caval, and sternal parts), membranous (pleuroperitoneal membranes), costal, retroglandular, aortic, and mesogastric. There are three permanent hiatuses, caval, esophageal, and aortic. The pleuroperitoneal canals are temporary hiatuses.

The transverse septal subdivision produces the pars sternalis and portions of the pars costalis and pars lumbalis. The membranous subdivisions become only small

segments of the pars costalis. Pleuroperitoneal hiatuses and pleuropericardial canals are obliterated by the growth of the subjacent organs. Bochdalek's lumbocostal triangles do not mark the site of closure of the pleuroperitoneal hiatuses. With regard to the surgically important matter of diaphragmatic hernia, Dr. Wells concludes that pleuroperitoneal-hiatus hernia and the so-called "congenital absence" hernia (absence of a dorsolateral segment of the diaphragm) are two grades of the same congenital anomaly, namely, abnormal persistence of the pleuroperitoneal hiatus.

Development of the human nephros. The adult mammalian kidney is formed from the last part only of the long series of primitive nephric rudiments which extend from the region of the 7th somite to the lumbar region. Because comparative anatomists have distinguished in lower forms of the vertebrate series a pronephros or head kidney, in certain intermediate forms (e.g. the amphibians) a mesonephros, and in mammals a metanephros, embryologists have tended to see a similar succession in the development of the mammalian kidney. It is true that the definitive kidney (metanephros) is preceded by a more or less well-defined mesonephros; but the existence of a discrete pronephros in mammals is hardly supported by the evidence. In most species only a few ill-defined pronephric tubules occur. In the human species it has been claimed that seven to nine pronephric tubules are formed, each extending itself caudally to join the one behind and thus to establish a common pronephric duct. This, if it actually occurred, would be quite exceptional among mammals.

Dr. Theodore W. Torrey, of Indiana University, devoted a sabbatical leave to a very careful re-examination of the pronephric rudiments in the embryos of horizons x to xii (7 to 29 somites) in the Carnegie Collection. In his report, which is a comprehensive review and restatement of the whole question, he reaches the conclusion that the concept of the pronephros does not apply to the human embryo. Although he does not object to the identification of the anteriormost rudiments as equivalent to the pronephros of the lower vertebrates (Anamnia), he considers that in man and other eutherian mammals the pronephros has no further reality; that is, it does not constitute a special organ or form an independent pronephric duct. All the rudiments (nephrons) form a continuous series. Only those which arise farther caudally than the seven to nine first rudiments join the independently arising nephric duct. The uppermost rudiments of the mesonephric region disappear, like their antecedent pronephric rudiments, and all occupy merely a time segment of a continuum. Applying these findings to the general concepts of comparative anatomy, Dr. Torrey considers that although the terms pro-, meso-, and metanephros have considerable descriptive usefulness, the entities they describe have no real significance other than as intergrading regions of a holonephros, i.e., general kidney sequence. The concept of a pronephros means little except in larval anamniotes; even the metanephros has reality only as the end product of the nephric sequence in amniotes.

Effect of estrogen on the uterine epithelium. In certain animals, e.g. the rat and opossum, it has been found that long-continued administration of an estrogenic hormone is followed by partial or complete replacement of the lining epithelium of parts of the reproductive tract by stratified squamous epithelium. This occurs in the rat's uterus, and according to the observations of Dr. R. K. Burns it takes place also in the urethra and bladder of the newborn opossum. The problem arises whether the change is a metaplasia, i.e. a local change, or rather a spread of squamous epithelium upward from the vaginal region.

When Dr. Gershon Gitlin, of the Hebrew University of Jerusalem, was at the Department of Embryology as a Visiting Fellow, he undertook at the suggestion of Dr. Burns to attack this problem by experiments on the rat. By implanting pellets of

estradiol dipropionate subcutaneously for 21 to 267 days, a chronic state of estrogen domination was produced. The treated animals exhibited both an extension upward of the stratified squamous epithelium of the lower uterine horns, and metaplasia of the epithelium distributed irregularly as foci which spread locally, replacing the adjacent columnar epithelium. Whether these foci develop from relatively undifferentiated cells of the columnar epithelium, or possibly from islets of surviving urogenital sinus cells which migrated upward during embryonic development, remains to be determined.

The germ cells of human embryos. A group led by Dr. Arthur T. Hertig, of Harvard Medical School, Research Associate of the Department of Embryology, and assisted by a grant from the Carnegie Institution of Washington, has published (see bibliography below, under McKay, Hertig, Adams, and Danziger) a study of the germ cells of human embryos using histochemical methods. This work supplements and extends the description of these cells and their migration worked out by Witschi (1948) from material in the Carnegie Collection. The Harvard group found that the cytoplasm of the embryonic germ cells exhibits high alkaline phosphatase activity, which presumably indicates a very active metabolic interchange with the surrounding tissues. By suitable techniques this fact can be used to produce a very distinctive staining reaction in the germ cells. Thus easily identified, germ cells were found in the primitive gut, mesentery, and coelomic mesothelium of the human embryo of 5 mm crown-rump length, and in the path of migration to the gonad as described by Witschi. In embryos of 23 and 35 mm these cells were also found in the root of the mesentery in the adrenal glands, and in sympathetic ganglia and nerve tissue at the hilum of the adrenal gland. The observations tend to confirm the view that in man as in other vertebrates the germ cells arise at a relatively early stage of embryonic differentiation, and migrate from their earliest sites toward their ultimate place in the gonads.

When a tumor of the kind known as dysgerminoma was subjected to tests for alkaline phosphatase, its cells reacted like the embryonic germ cells, thus confirming the supposition that such tumors originate from germ cells.

Localization of erythrocyte-forming areas in the chick. Dr. George W. Settle, of the Johns Hopkins Hospital, while an undergraduate student of biology at the Johns Hopkins University, began under Dr. Nelson T. Spratt's direction a study of the localization, in the early chick blastoderm, of those cells which are later to form red blood cells. The work being unfinished when Dr. Settle transferred to the Medical School, he requested space and facilities in the Department of Embryology and continued his research as time permitted. By cutting chick blastoderms, from the beginning of incubation to 40 hours, into small portions and growing them in vitro, he found that determination of the hemoglobin-forming potentiality occurs before the appearance of the embryonic shield in the pre-primitive-streak blastoderm. The region in which this potentiality develops begins as a half-ring-shaped area in the caudal part of the blastoderm and spreads into a U-shaped band at the sides of the embryo almost to the head end at the 6-somite stage.

From this time on, the progress of blood-cell and blood-vessel formation in the blastoderm and embryo is well known. Dr. Settle's contribution therefore extends the history of the blood-forming area back to its beginnings.

Designation of the intersegmental arteries. The serial numbering of the arteries related to the cervical and occipital somites presents a puzzling situation for two reasons: (1) The occipital segments are inconsistent because the proatlantal vertebral element, constant in some mammals, is in man usually attached to the odontoid process of the axis; (2) the definitive cervical segments are produced by union of tissues

from the lower half of one somite and the upper half of the next. Attempts to number the arteries related to the segmental nerves have resulted in confusing discrepancies. In a careful review of the literature and of the underlying facts, Mrs. Dorcas H. Padget, Fellow in the Department of Embryology 1946–1951, arrives at the conclusion that the best solution is to designate the artery which accompanies the first cervical nerve by the term *proatlantal* (suggested by Arey), or to call it the *suboccipital intersegmental artery*. In the adult human body this becomes the transverse suboccipital part of the vertebral artery. The next of the series, the first properly called cervical intersegmental, is that associated with the second cervical nerve. The artery which becomes the stem of the subclavian and vertebral arteries is the sixth cervical intersegmental artery, accompanying the seventh cervical nerve.

Pathology of Embryo and Fetus

Early embryonic abnormality. Among the large collection of early embryos of the rhesus monkey made by Dr. Carl G. Hartman and studied chiefly by Dr. C. H. Heuser and the late Dr. G. L. Streeter, there are a number of abnormal embryos. Of these, nine are of special value because the embryos are accompanied by samples of the uteri in which they were implanted and by sections of the ovaries. The embryos were of accurately known age, 10 to 12 days after ovulation. The tissues were examined by experienced specialists with respect to the condition of the embryos, the endometrium, and the corpus luteum of pregnancy, and it is possible to make a well-informed conjecture as to the primary seat of the disorders which led to abnormality of the embryos.

Dr. George W. Corner and Dr. G. W. Bartelmez found that in four or five of these cases the embryo is retarded or deformed, but the corpus luteum and the endometrium are histologically normal and show characteristic cytological changes appropriate to the corresponding stage of pregnancy. In short, there is no evidence that the maternal environment was abnormal through disease or endocrine deficiency, and the embryonic abnormality must be attributed to constitutional defects of the embryo itself. In the other cases the possibility exists that abnormality of the embryo resulted from primary failure of the corpus luteum, with consequent inadequacy of the uterine lining to support the developing embryo.

Experimentally induced female pseudohermaphroditism. Dr. L. J. Wells, of the University of Minnesota, during his stay at the Department of Embryology joined Dr. Gertrude van Wagenen, of Yale Medical School, in the study and analysis of ten cases of pseudohermaphroditism produced in female rhesus monkeys by injecting the pregnant mother with androgenic hormones, usually in a dose of 25 mg per day for about 30 days in the second and third months of gestation. Masculinizing effects ranged from slight to marked. Two control fetuses were studied for comparison. In the experimental animals the distal portion of the vagina was absent. The reproductive tract included such structures as an elongated urogenital sinus, a prostate gland, and seminal vesicles. The induced modifications persisted into adult life in four of the animals which were kept for several years. The treatment did not cause the ovaries to differentiate into testis-like structures, nor did it prevent formation of the usual derivatives of the Müllerian ducts (oviducts, uterus, upper vagina). The intersexual condition in these monkeys was qualitatively different from that in the bovine freemartin.

Implantation, Placenta

Relation of the implanted blastocyst to the uterus. The work of Dr. B. G. Böving on the factors governing the attachment of the blastocysts of the rabbit to the uterus was abstracted at some length in last year's report (Year Book No. 53), and

it was presented fully in the June 1954 Cold Spring Harbor Symposium on Quantitative Biology (vol. 19 of the Symposium series). Dr. Böving pointed out a systematic sequence of anatomical steps between the entry of the blastocysts into the uterus and the establishment of the placenta, and he outlined mechanical, chemical, and biological mechanisms which appeared responsible for each step. Study is continuing on the details of several of these steps, namely, blastocyst transport, adhesion between blastocyst and uterus, the carbonate or bicarbonate transfer with its alkaline reaction and silver precipitation, and the invasion of the maternal epithelium by trophoblast.

Venous drainage of the placenta of the rhesus monkey. An article by Dr. Elizabeth M. Ramsey in volume 35 of the Contributions to Embryology presents in definitive and fully illustrated form the results of her long study of the venous drainage of the placenta of the rhesus monkey. Pending the publication of this work, Dr. Ramsey went on to study the same question in the human placenta, as mentioned in last year's report (Year Book No. 53) under "Research in Progress." The pattern proves to be much the same in both monkey and man, and a summary of this published report would be essentially similar to that of the study on the human species (as yet incompletely published) given in the last report. Dr. Ramsey's observations form the basis of an interpretation of the circulation through the placenta which does not demand any such special arrangements as have been postulated but not conclusively demonstrated by previous writers (e.g. Bumm, Spanner). In her view, arterial blood enters from numerous vessels at the base of the placenta, and venous blood is drained off through numerous basal veins as well as about the placental margin. The venous orifices are not usually contiguous to the arterial stomata, and the afferent and efferent blood streams are kept separate by pressure differentials and by the multitude of obstructing villi.

Passage of sugars across the monkey placenta. The team led by Dr. A. St. G. Huggett and Dr. S. R. M. Reynolds during the former's visit in 1954–1955 have published a preliminary account of part of their work (see under Chinard *et al.* in the bibliography below). They used a method devised by Dr. Reynolds (Reynolds, Paul, and Huggett, in bibliography) by which samples of fetal and maternal blood can be obtained simultaneously without great disturbance of placental function. This method, which was briefly described in the previous annual report (Year Book No. 53), makes use of the fact that the rhesus monkey has a placenta with two lobes connected by blood vessels. It is possible to locate these interlobar vessels, cut down upon them, and cannulate the artery, thus obtaining blood samples without loss of amniotic fluid or a fall of intrauterine pressure. The method promises to be very useful in the study of fetal physiology.

It was found that the resting pregnant monkey has normal amounts of blood glucose. The fetal blood glucose is usually somewhat less than that of the mother. Glucose injected intravenously into the mother appears rapidly in the fetus, without a rise of blood fructose in either fetus or mother. Labeled glucose given intravenously to the fetus appears rapidly in the maternal blood. Labeled fructose given to the mother appears rapidly in the fetal blood; its rate of appearance there is impaired by the administration of glucose to the mother. The monkey placenta, therefore, unlike that of the sheep, which was previously studied by Dr. Huggett, does not form appreciable amounts of fructose from glucose. The back flow of glucose from fetus to mother goes on independently of the flow from the mother to the fetus, but fructose given to the mother seems to be transported by the same carriers as those which carry glucose to the fetus.

Fetal and Neonatal Circulation

Circulation rates. When Dr. S. R. M. Reynolds was at Oxford in 1950–1951 on a Guggenheim fellowship, he joined forces with the staff of the Nuffield Institute for Medical Research in a study of the blood circulation in fetal lambs by the aid of cineradiography. The very extensive results of his study have been published in a number of articles previously mentioned in these annual reports. In volume 35 of the Contributions to Embryology Dr. Reynolds and Dr. G. M. Ardran and Dr. M. M. L. Prichard, of Oxford, give a definitive report, with full tabulation of their data, on the regional circulation times in the fetal and neonatal lung.

When the lungs are first inflated at birth, the blood flow through the lungs becomes much more rapid and increases fourfold in volume. This change is associated with an increase of the cross-sectional area of the lung vessels. There is a predominant increase in blood flow to the head also, and a diminution of flow to the caudal parts of the animal. In the fetus before inflation of the lungs, the slow cephalic flow is partly compensated for by the high oxygen concentration in that part of the blood which is directed to the head.

Although the velocity of flow through the pulmonary artery is greatly increased after inflation of the lung, the flow through the pulmonary circuit as a whole is not much changed because of the increased capacity of the capillary and venous bed. The velocities of flow through intestine, liver, and kidney are of the same general order of magnitude before and after aeration of the fetal lungs. The flow through the placenta is relatively fast before aeration, as is that in the shortest circuit through the fetus from the umbilical vein to the umbilical artery.

Architecture of the umbilical cord. Dr. Anna W. Chacko, a Visiting Fellow from Pakistan, during her stay at the Department of Embryology joined Dr. Reynolds in a study of the human umbilical cord. This structure has always interested embryologists because of its obvious importance, but the details of its anatomy have been rather neglected. Recent progress in understanding the fetal circulation has shown, however, that the cord is more than a mere conduit for the fetal blood supply, actually being an essential part of the mechanism by which the fetal circulation is maintained. Dr. Chacko and Dr. Reynolds have worked out the pattern of the contractile fibers (i.e., smooth muscle and elastic tissue) in the walls of the umbilical arteries and veins, in both distended and constricted (empty) vessels. They have also measured the thickness of the various layers of the vessel walls in these two opposite states.

The facts thus elicited, which are fully detailed in the article, suggest that constriction of the umbilical artery is the result of forces imposed by the architectural pattern of the tissues. It is produced by shortening of the muscle fibers, which are arranged in interlacing bundles, so that their contraction produces a twisting or wringing action, more technically designated by the authors as rotational shortening, with consequent thickening of the tissues of the arterial wall and temporary obliteration of the lumen. A theoretical calculation from the cross-sectional area of the arteries in the human cord shows that an umbilical artery when it is completely constricted is about 17 per cent shorter than when fully distended. The calculation was confirmed by direct observation on the umbilical cords of fetal lambs at Caesarean section. This shortening causes thickening of the connective tissue of the cord (Wharton's jelly) and makes it a conspicuous feature in the emptied cord, whereas when the vessels are distended as in life the Wharton's jelly is stretched into thin layers in the interstices between as well as about the vessels.

Myometrium

Excitability of uterine muscle. Frequent reference has been made in these annual

reports to the program of investigation of the physiology and biochemistry of uterine muscle, led by Dr. Arpad Csapo. In the course of his experiments Dr. Csapo noticed certain variations of contractile response with changing rate and intensity of electrical stimulation, which have now been subjected to systematic study by Dr. Csapo and Dr. Marcus C. Goodall, of the University of Michigan.

Strips of rabbit's uterine muscle suspended in physiological salt solution attain maximum tension when stimulated with alternating current of frequency 30 and 100 per second for 5 seconds. The fact that maximum response requires so long a duration of stimulation suggests that activation of the muscle occurs slowly, preceding the development of tension. This suggestion was confirmed by the observation that there is a continuous increase in the elastic modulus during the period of stimulation.

When the field strength of the stimulating current was varied, uterine muscle from rabbits under progesterone domination was found to have a significantly higher threshold for electrical stimulation than estrogen-dominated muscle.

The relation between length of the muscle sample and the tension developed, which is well known for skeletal muscle, was studied. Maximum tension is obtained in all cases at the resting length. The kinetics of isotonic shortening of the uterus was studied as a function of load and was found to obey the equation developed by A. V. Hill from observations on skeletal muscle.

Behavior of uterine muscle in the intact animal. As shown by Csapo and Corner, in investigations reported in the Year Books of the past five years, the behavior of isolated strips of uterine muscle, studied in vitro, is under the control of the ovarian hormones. The amount of tension developed on electrical stimulation, the form of a single contraction-relaxation curve, and the response to frequent regularly repeated stimulation (positive vs. negative staircase phenomenon) all differ systematically according to whether the uterus is dominated by estrogen or progesterone.

Dr. Brenda M. Schofield, while a Visiting Fellow in the Department of Embryology, studied the same question in the intact uterus in situ. In the anesthetized rabbit, a loop of the uterus was enclosed in a plexiglass chamber so designed that the loop could be stimulated electrically, and the tension developed by the resulting contractions could be registered on a kymographic drum. The pattern of contractility elicited by altering the strength and frequency of electrical stimulation was found to vary in the same way as that in isolated strips under the same conditions. The form of the contraction wave, the relation between tension and strength of stimulus, and the direction of the staircase all depend on the action of estrogen or progesterone, respectively. This finding, even though the effects are not so regular in the intact animal as in the isolated strips, because of superimposed minor effects of nervous and circulatory factors, is nevertheless so clear as to validate the application of results obtained from the muscle strips in theoretical analysis of the physiology of the uterus.

DIFFUSION AND POPULARIZATION OF RESULTS

Lectures and conferences. Dr. R. K. Burns presented lectures on the hormonal control of sex differentiation before the Sigma Xi Society at the University of North Carolina, Chapel Hill, in December 1954, and at the University of Virginia, Charlottesville, January 1955. He also spoke on the same topic at a seminar of Florida State University, Tallahassee, in April, and at a meeting of the Chagas Society of the University of Georgia Medical School, Augusta, May 1955.

Dr. David W. Bishop gave seminar talks at the Department of Biology, Johns Hop-

kins University, on mammalian antigens and fertilization, and at Swarthmore College on sperm metabolism in vivo.

Dr. Bent G. Böving discussed his current work at a meeting of the Biology Club of Johns Hopkins University, May 1955.

While abroad in July–September 1954 on his Guggenheim fellowship, Dr. Arpad Csapo gave the Holme Lecture at University College, London. He also lectured at the following institutions: St. Mary's Hospital, London; the Department of Pharmacology, Oxford; University of Manchester; University of Edinburgh; Collège de France, and Department of Biochemistry, Sorbonne, Paris; Danish Obstetrical Society, Copenhagen; Max Planck Institute, Heidelberg.

Dr. Corner presented an address on medical education ("The Other End of the Log") before the annual alumni meeting of the University of Rochester Medical School, October 1, 1954. He participated as lecturer in the Los Angeles Obstetrical and Gynecological Assembly, February 1955 (four lectures on topics in embryology and the physiology of reproduction), and while in southern California also gave two lectures at the University of California at Los Angeles. In May 1955 he addressed a meeting of the Middle States Pathological Society at Washington, basing the lecture on the material of the Carnegie Collection of human embryos.

Dr. Gilbert S. Greenwald discussed his work on the effects of estrogen on early embryos before a meeting of the Society for Experimental Biology and Medicine at the Army Chemical Center, Aberdeen, Maryland, in June 1955.

Dr. Elizabeth M. Ramsey gave lectures on placental circulation at the State University of New York, College of Medicine, Brooklyn, November 1954, and on the pathology of abortion at Sinai Hospital, Baltimore, January 1955. She took part in the M and R Pediatric Research Conference on Respiration in the Premature Infant, Chicago, December 1954; the Macy Foundation Conference on Gestation, Princeton, March 1955; and a conference on microcirculation problems held at the annual meeting of the American Association of Anatomists, Philadelphia, April 1955. At all these conferences Dr. Ramsey dealt with various aspects of the placental circulation.

During his stay at Recife, mentioned above, Dr. S. R. M. Reynolds gave a course of lectures on the physiology of reproduction, and at Montevideo he presented a series on fetal physiology. In October 1954 he was visiting lecturer for three days at Wayne University, Detroit, speaking on the physiology of the uterus. In June 1955 he took part in a symposium on reproduction and fertility at the Centennial of Michigan State College, East Lansing. He was also a participant in the M and R Conference on Respiration in the Premature Infant, Chicago, December 1954, and the Macy Foundation Conference on Gestation, Princeton, March 1955. Dr. Reynolds also gave lectures at several institutions in Baltimore and Washington.

At the 1954 Cold Spring Harbor Symposium on Quantitative Biology, which dealt this year with physiological aspects of development, five members of the Department of Embryology presented papers or took part in the discussions. The contributions of two of these, Dr. Reynolds and Dr. Böving, have been mentioned elsewhere in this annual report. The others were Dr. D. W. Bishop, Dr. R. K. Burns, and Dr. E. M. Ramsey.

Reviews and general articles. An article by David W. Bishop on sperm maturescence, in the *Scientific Monthly,* includes the results of some of his own studies as well as a review of work by others.

The long-promised work, *Analysis of Development,* by various American authors under the editorship of Willier, Weiss, and Hamburger, contains a chapter on the urinogenital system by Dr. R. K. Burns, covering a field of research in which Dr. Burns himself has been one of the leading contributors through research which has been reviewed in the successive

annual reports of the Department of Embryology during the past fifteen years.

A paper given by Dr. Arpad I. Csapo at the International Congress of Gynecology and Obstetrics at Geneva, Switzerland, July 1954, constituted a general review of his studies on the physiology of uterine muscle with special reference to disorders of gestation and labor caused by muscular inertia and other malfunction having a chemical and physical basis.

Dr. Reynolds and two of his former associates at the Department of Embryology, Dr. J. S. Harris and I. H. Kaiser, are coauthors of a comprehensive treatment in book form (see bibliography) of the clinical measurement of uterine forces in pregnancy and labor. This book is based largely on experience with the tokodynamometer developed by Dr. Reynolds, but also covers the history of the subject and the other methods which have been used in recording and measuring the motility of the uterus as a functioning organ.

As opening speaker of the 1954 Cold Spring Harbor Symposium on Quantitative Biology, Dr. Reynolds discussed the relation between developmental changes and the future requirements of the embryo, citing instances in which anatomical and physiological changes occur in the developing organism, of such kind that physiological needs as yet unexpressed are provided for in advance. For this remarkable provision of nature Dr. Reynolds and Professor R. G. Harrison, of Liverpool, England, have proposed (after consulting a classical scholar) the term "prophthasis," which conveys the idea of anticipatory provision.

Dr. Reynolds published in the *American Journal of Obstetrics and Gynecology* a useful summary of studies on the hemodynamics of fetal circulation, based largely on research by himself and his associates which has been reported in these Year Books during recent years.

Three members of the Department made valuable contributions to the *Handbook of Biological Data* now being published under the auspices of the National Research Council and the American Institute of Biological Sciences. Dr. G. W. Bartelmez contributed a table of the development of the eye. Dr. D. W. Bishop collaborated in the preparation of two tables: no. 105, Metabolic Interrelationships: Carbohydrates, Fats, and Protein; and no. 106, The Krebs Cycle. Dr. B. G. Böving planned and compiled an outline for a comprehensive table of the events of human development from the beginning of embryonic life to old age.

Photography. Richard D. Grill, photographer, received the first prize for a color photomicrograph of a living rabbit egg at the Twenty-fourth Annual Meeting of the Biological Photographic Society, Atlantic City, September 1954. Two salon prints of early embryos, 17 and 44 days, were accepted by the Tenth International Salon of Nature Photography, Chicago, February 1955. Two salon prints were chosen for exhibition in the highly selective Nineteenth Rochester International Salon on Photography, March 1955, and two were designated "honor prints" at the Buffalo International Exhibition of Nature Photography, May–June 1955.

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DEPARTMENT OF GENETICS

Cold Spring Harbor, Long Island, New York

M. DEMEREC, *Director*

When the Department of Genetics was established, in 1904, one of the primary reasons for locating it at Cold Spring Harbor was that the Biological Laboratory was already operating there as a department of the Brooklyn Institute of Arts and Sciences, with the financial support of interested members of the community. From the beginning the two organizations had many interests in common. They were neighbors, both situated at the southwestern tip of the harbor on grounds leased from the Wawepex Society. They were both concerned with biology, the Department with research in experimental evolution and the Laboratory with summer research in experimental biology and the teaching of marine and field biology. For many years they had a common director. It was not until 1941, however, during the early part of Dr. Bush's administration, that a plan was evolved to co-ordinate the programs of the two laboratories. At that time Dr. Bush, as President of the Carnegie Institution, and Mr. Arthur Page, as President of the Long Island Biological Association, which since 1924 had been operating the Biological Laboratory, worked out an informal agreement whereby the activities of the Department of Genetics and the Biological Laboratory were co-ordinated. As a result of this agreement, M. Demerec was appointed director of the Biological Laboratory; and a year later, when he was put in charge of the Department of Genetics as well, the development of the present dual program became possible.

At the time these plans were being contemplated, the future of the Biological Laboratory was uncertain, and serious consideration had been given to the possibility of terminating its work. The question had also been raised whether the research activities of the Department of Genetics might not be more effectively carried on in some other locality, closer to other research groups. By now, both these problems have to a large extent been resolved. Collaboration with the Department of Genetics has placed the Biological Laboratory in a favorable position to obtain funds for its research activities, thus overcoming one of its major difficulties. At the same time, the development at the Laboratory of a research program complementing that of the Department of Genetics has strengthened both groups. Adaptation of the operation of symposia and other summer activities of the Laboratory in accordance with the new program, moreover, has brought to Cold Spring Harbor leading scientists active in a broad range of research areas interesting to the Department, and thus has provided our staff an unusual opportunity for establishing new contacts and obtaining firsthand information about many current research problems. As a further step in strengthening the ties between the two laboratories, the recently completed building program of the Department of Genetics included a jointly used lecture hall, which adds greatly to the comfort of symposium meetings and facilitates arrangements for seminars, conferences, and public functions.

Under these circumstances it is logical for the Board of Directors of the Long Island Biological Association and the staff of the Biological Laboratory to join the staff of the Department of Genetics in expressing appreciation to Dr. Bush, in the year of his retirement, for what has been accomplished at Cold Spring Harbor during his administration. The Symposium dealing with "Population Genetics," held June 6–13, 1955, was dedicated to Dr. Bush, and expressions of appreciation were

extended to him at the last session of the meetings by President Amyas Ames, speaking on behalf of the Long Island Biological Association, and M. Demerec, representing the scientific staffs of the two laboratories. At that session, attended by about two hundred persons, I. M. Lerner, of the University of California, presented a concluding survey of the symposium meetings.

Research

Knowledge of the kinds of chromosomal elements, present in the maize complement, that serve to control gene action and to induce changes in this action has been considerably expanded during the past year by McClintock. A number of different elements, or systems of interacting elements, each exercising a specific mode of control over gene action and changes in gene action, have now been identified. These elements may be recognized because they undergo transposition from one location to another within the chromosome complement without losing their specificity. Thus, the action of genic materials at one particular locus may be controlled by different elements, as a result of independent insertions of such elements at the locus. Or, conversely, the genic substances at different loci may come under the control of one particular element. With few exceptions, the changes these elements effect do not appear to alter the basic structure or organization of the genic substance itself. Rather, they serve to modify its action in a controlled manner and in particular cells of the organism. Their influence on gene action can range from slight and subtle modifications to total inhibition. Some of the recent evidence obtained in this study suggests that controlling elements are present at some of the known gene loci of the standard chromosome complement of maize; and that they control the action of these genes during development of the organism, and are responsible, in addition, for changes in their modes of expression—that is, for observed mutations.

Kaufmann and his associates have previously reported that solutions of crystalline ribonuclease in which onion roots are growing gradually acquire the ability to degrade deoxyribonucleic acid in sections of fixed tissues. They have now interpreted this information as indicative of a ribonucleic acid–deoxyribonucleic acid complex in the chromosomes of the fixed root and of a deoxyribonuclease–ribonucleic acid complex in the cytosomes of the living root-tip cells, the ribonucleic acid presumably acting as an inhibitor of the enzyme.

Electron microscope studies of third-instar salivary-gland cells of *Drosophila* by Gay have afforded evidence of the polytene nature of the chromosomes, the subsidiary strands having a diameter of about 500 A and being arranged in a hierarchical assembly of intertwined pairs of pairs. The nuclear membrane in these cells is double-layered, and characterized by a reticulate sculptured pattern, showing less dense material surrounded by denser "circular" areas about 500 A in diameter. Gay has also found in these cells structural evidence suggesting a mechanism whereby outpocketings from the nuclear membrane, associated with the chromosomes, are released into the cytosome to form the cytoplasmic organelles known as the endoplasmic reticulum. Participation of the membrane in nuclear control of cytoplasmic function had not been detected by previous students of nucleo-cytoplasmic interrelations, and this observation provides a new perspective on problems of gene action.

The action of cytochrome c, a basic hemoprotein, in reducing basophilia of tissue sections has been investigated by McDonald, Kaufmann, and associates. They found that basicity per se is not the determining factor, since lysozyme, another basic protein, does not reduce basophilia of tissue sections, whereas hemoglobin, another hemoprotein, does. All three proteins increase staining with acidic dyes.

McDonald has continued her investigations in the development of procedures for the purification of calf-spleen deoxyribonuclease. Although a considerable degree of purification of the enzyme has been effected, crystallization has not yet been achieved. As the preparations are purified, marked changes occur in their mode of action, suggesting that several enzymes capable of degrading deoxyribonucleic acid may be present. Inhibitors are apparently being removed during the purification process. In continuation of her studies on the specificity of action of crystalline pancreatic ribonuclease, McDonald has shown that the hydrolysis by this enzyme of cyclic 2′:3′-phosphates of pyrimidine nucleotides, unlike the degradation of apurinic acid reported last year, is a specific property of pancreatic ribonuclease.

Chemical studies of bacteriophage by Hershey's group have provided further evidence of the genetic role of viral nucleic acid. The substance that initiates viral infection is at least 95 per cent pure nucleic acid. This nucleic acid increases in amount in infected cells before viral-precursor protein begins to form. Furthermore, substances, such as chloramphenicol, that inhibit protein synthesis do not interfere with the formation of nucleic acid, and nucleic acid "purified" in this way behaves like normal virus precursor. These results show that nucleic acid—presumably virus genetic material—is not synthesized inside a viral membrane, and that it can carry out its functions without assistance from associated protein.

Witkin has completed additional analyses of the composition of *Salmonella* clones in which transduction has occurred. New evidence strengthens the interpretation that incorporation of the genetic specificity of the donor strain into the genotype of the recipient usually takes place in a single daughter cell within one or two divisions after infection.

In work on induced mutation, Witkin has gained new information about the timing of the process, and about its susceptibility to metabolic influences. She has shown that ultraviolet-induced mutations from nutritional requirement to prototrophy in *Salmonella* do not require an extensive period of postirradiation division for their expression, as had been believed previously. In a re-evaluation of the "delayed effect," she has demonstrated that the yield of induced mutations is determined irreversibly during a critical period corresponding to the first third of the first division after irradiation. During this sensitive stage of the lag phase, presumably the period of chromosome duplication, the ultimate frequency of induced mutants can be varied over a range of at least 500 per cent by altering the temperature, or the concentration of specific metabolites in the growth medium. A high concentration of amino acids during the critical period appears to be a major requirement for the production of induced mutants.

Using transduction as a tool, Demerec and his collaborators have been able to carry out genetical analyses of short regions of the chromosome complex of *Salmonella typhimurium*. They have found that all the known tryptophane, cystine, and methionine loci, numbering thirteen, are closely linked. Their studies have revealed that the gene loci investigated are not distributed randomly along the chromosome, but rather that certain genes associated with related functions are arranged in series. For example, in the case of four tryptophane loci, not only are they linked together, probably adjacent to one another, but their order on a linkage map coincides with their sequence in respect to biochemical blocks in the chain of reactions leading to the synthesis of tryptophane. An analysis of four histidine loci by Hartman has yielded similar results; and still-uncompleted studies of methionine, adenine, adenine-thionine, proline, isoleucine, and isoleucine-valine loci also indicate specific linkage arrangements. This suggests that certain gene arrangements have selective advantage and have

been developed during a long series of evolutionary readjustments.

Demerec and Lahr have succeeded in effecting transformation of several genetic markers in *Salmonella,* using as donor material either disintegrated bacteria or deoxyribonucleic acid extracted from such bacteria. Their results indicate that mutations are frequently induced during preparation of the donor material.

Studies of spontaneous mutation in steady-state populations of *Escherichia coli* have been continued by Moser, working with the chemostat. A series of experiments, using nitrogen as the controlling growth factor in histidine-supplemented lactate medium, was carried out to obtain more precise data bearing on the correlation between generation time and spontaneous-mutation rate. It was found that the higher hourly mutation rate observed with higher growth rate is apparently proportional to the rate of cell division. Moser concluded that this increase in mutability is possibly paralleled by an increase in the amount of ammonium salt assimilated per cell produced.

Staff

Evelyn M. Witkin resigned from the Department as of August 31, 1955, and transferred her research program to the Department of Medicine at the College of Medicine of the State University of New York, at which institution her husband heads the Psychology Laboratory. Witkin joined our group in 1945, to do research for her thesis as a graduate student in Columbia University, and remained with us first as a fellow and later as a member of the staff. She came to work in bacterial genetics, shortly after we had begun research in that field, and during her stay here she took a prominent part in the development of the bacterial genetics program. Working with *Escherichia coli,* she developed an ingenious technique which enabled her to establish that resistance to ultraviolet radiation arises as a result of spontaneous mutation, the radiation serving as a passive selective agent. The rate of occurrence of such mutations was estimated as 1×10^{-5} per bacterium per generation. A radiation-resistant strain, B/r, isolated by her is being used extensively in research. Witkin was among the first to study the induction of mutations in bacteria by treatment with chemicals, and she found that three of the four chemicals she tested at that time (sodium deoxycholate, pyronin Y, and acriflavin) were mutagenic. She was also the first to obtain evidence that the nucleus of the bacterial cell is actually a carrier of hereditary material, and to demonstrate the action of a suppressor mutation in *E. coli.* Witkin has devoted a considerable amount of attention to studies of population dynamics in bacterial cultures consisting of mixtures of B and B/r bacteria. Recently, her interest has been concentrated on studies of the delayed appearance of induced mutants, and of the kinetics of transduction in *Salmonella.* Conclusions reached in this work are summarized by her report in this Year Book. We hope that collaboration will continue between Dr. Witkin and the members of our staff.

The Department had three fellows in 1954–1955: Alan Garen, who continued working with Hershey under an extension of his fellowship from the National Foundation for Infantile Paralysis; Hermann Moser, a Carnegie Institution Fellow, working in Demerec' laboratory for a second year; and Royston C. Clowes, a Research Fellow of the Damon Runyon Memorial Fund, who joined Demerec' group in June 1955. During the summer of 1955 Dr. Joseph S. Gots, of the University of Pennsylvania, spent two months as a guest of the Department, carrying out biochemical analyses of bacterial mutants.

Co-operative Work

We have continued to work in close cooperation with colleagues at the Biological Laboratory of the Long Island Biological Association. The eight members of the

Laboratory research staff took part in our weekly staff meetings; and they and their assistants attended our seminar lectures. A major portion of the year-round research at the Biological Laboratory deals with genetical problems related to those studied at this Department. V. Bryson, P. D. Skaar, and E. Englesberg worked during the past year in the field of bacterial genetics; and B. Wallace and J. C. King continued their studies of population genetics with *Drosophila*.

We also profited by association with visiting research workers who stayed at the Laboratory for various periods. Among these were: Mark Adams and Alan Bernheimer, of the New York University College of Medicine; S. Granick, R. D. Hotchkiss, and K. Maramorosch, of the Rockefeller Institute for Medical Research; S. E. Luria, E. S. Lennox, Dorothy Fraser, and their associates from the University of Illinois; A. H. Doermann and his associates from the University of Rochester; A. Novick, of the University of Chicago; U. Fano, of the Bureau of Standards; D. Miller, of the University of Nebraska; and E. D. DeLamater, of the University of Pennsylvania.

Members of our staff have co-operated in various ways with scientists at other institutions. Kaufmann and Gay made use of electron microscopes at the Rockefeller Institute and at Brookhaven National Laboratory; McClintock utilized facilities of the Biology Department at Brookhaven National Laboratory for drying her corn seed; and Garen collaborated with Dr. N. Zinder, of the Rockefeller Institute.

Meetings and Lectures

The twentieth Cold Spring Harbor Symposium on Quantitative Biology, held in June 1955 at the Biological Laboratory, was attended by almost two hundred scientists interested in population genetics. More than forty of the participants were from foreign countries, including Great Britain, France, Germany, Sweden, Italy, Yugoslavia, Holland, Spain, Japan, Korea, Australia, Uganda, South Africa, Brazil, and Chile. Members of the staffs of both laboratories took part in discussions and in the program.

In August 1955 a conference of scientists interested in research with bacterial viruses was held at Cold Spring Harbor. It was organized by Hershey and Burgi, and attended by more than seventy participants.

Weekly meetings of the research staffs of the Department of Genetics and the Biological Laboratory were held from October to May, for informal discussion of scientific problems of general interest and for reports of the current research of individual members. Seminar lectures also were scheduled each week throughout most of the year. They were attended by the scientific members of the Department and the Laboratory, and occasionally by scientists from near-by institutions. The speakers, who included staff members, members of the summer group, and invited guests, presented reviews of completed research problems in which they had made major contributions.

Drosophila Stocks

In 1935 a *Drosophila melanogaster* stock center was established at this Department, in order that collections of important stocks might be maintained in at least two laboratories in the United States, namely, at Pasadena and at Cold Spring Harbor. It was expected that this arrangement would minimize the chances for loss of stocks and also, with one center located on the west coast and the other on the east, would make them readily available to *Drosophila* workers.

During the twenty years the arrangement has been in effect, it has fulfilled these expectations and has rendered a significant service to *Drosophila* investigators. In the course of this period, however, there has been a considerable shift of emphasis in *Drosophila* research, and re-

cently it became desirable to examine the advisability of continuing the *melanogaster* stock center at our Department. One important aspect of the question was the fact that very few *melanogaster* stocks are now used in research by members of our laboratories, and that consequently the chances of deterioration and contamination were fairly high. Another factor was that requirements have changed with regard to the genetic constitution of stocks used widely in research, so that a collection which was appropriate twenty years ago may not be so at present. In addition, air mail service is now so rapid that the geographic location of a stock center does not play a significant part in the efficiency of its service. After bringing this problem to the attention of *Drosophila* workers by a note in *Drosophila Information Service,* and discussing it with representatives of the Pasadena laboratory and a number of other *Drosophila* workers, we decided to discontinue the research stock center at our Department.

During the past decade, in addition to supplying stocks for research, we have been sending them to high schools and universities for teaching purposes. A large proportion of the 1234 cultures sent out this year was used in teaching. This service, which is performed free of charge, requires only a small number of stocks, and will be continued.

Other Activities

The twenty-eighth issue of *Drosophila Information Service,* a mimeographed bulletin compiled from the contributions of *Drosophila* research workers in all parts of the world, was prepared at the Department with Demerec as editor. Witkin continued to compile and edit the *Microbial Genetics Bulletin,* of which numbers 11 and 12 were issued during the year.

The Drosophila Stock Center, under the care of Mrs. G. C. Smith, sent out a total of 1234 cultures to research and teaching laboratories requesting them. Of these, 75 cultures were shipped to Asia, Australia, Canada, Europe, and South America.

In the library, with Mrs. H. H. Wheeler as librarian, 2062 books were accessioned during the year. Of these, 65 were obtained by purchase, 34 were gifts, 144 were bound periodicals, and the rest were books acquired by the Department in recent years and held in storage during the reorganization of our expanded library facilities. They included 889 volumes from the former Nutrition Laboratory of the Carnegie Institution in Boston, 257 from the Biological Laboratory of the Long Island Biological Association, 108 from the former Genetics Record Office, and 565 from the Charles B. Davenport collection. The number of periodicals and serial publications received regularly was 351. Interlibrary loan service was received from Columbia University, New York Academy of Medicine, The Rockefeller Institute for Medical Research, and Brookhaven National Laboratory. Photostats were procured from Columbia University. Books and periodicals from our library were loaned to Brookhaven National Laboratory, University of Rochester, University of Vermont, University of Minnesota, Bristol Laboratories, and a few individuals in addition to members of this Department and the Biological Laboratory.

GROWTH AND INHERITANCE IN BACTERIOPHAGE

A. D. Hershey, Elizabeth Burgi, Alan Garen, and Norman Melechen

During recent years the work with bacteriophage has been guided by the following questions: (1) Is nucleic acid the sole agent of genetic continuity in bacteriophage T2? (2) Is multiplying T2 a structure of molecular dimensions, or does it resemble the extracellular form of the virus, which measures 65 mμ in least diameter and is bounded by a protein membrane? (3) How can one investigate the

relation that must exist between structure and function in genetic material? The study of genetic interactions between dissimilar viruses, and between viruses and their host cells, has brought to light a bewildering variety of relations. These include interconversion (of nucleic acid), substitution, modification, incompatibility, synergism, functional coexistence, and, apparently, simple cross contamination. Two genetic principles are serving to bring order out of this confusion. They are structural homology and functional compatibility. Recent discoveries suggest possible ways to bridge the gap between these genetic principles and the chemistry of nucleic acids.

The work summarized below has a direct bearing on all these questions. It was supported in part by a grant (C-2158) from the National Cancer Institute of the Institutes of Health, U. S. Public Health Service, and by a fellowship to Garen from the National Foundation for Infantile Paralysis. We received valuable assistance from Miss Carole Lyons, in charge of laboratory services, and from Mr. Henry Jones, Department photographer, who prepared many radioautographs.

Protein Content of T2

The experiments of Hershey and Chase, previously reported, showed that deoxyribonucleic acid is the principal component of the virus to enter the cell at the start of infection. One way of defining genetic material, therefore, was to analyze the viral nucleic acid for associated substances.

We have recently completed an examination of the viral proteins. We find two components in addition to the membrane protein.

The membrane protein, defined as material sedimentable after osmotic shock, adsorbable to bacteria, and precipitable by antiphage, amounts to about 95 per cent of the total viral protein. The remainder can be separated into fractions soluble and insoluble in trichloroacetic acid.

The acid-insoluble fraction, comprising 3 per cent of the total protein, resembles membrane protein in amino acid composition, but differs from it antigenically. It does not seem to be combined with the nucleic acid.

The acid-soluble fraction, including all material of low molecular weight in the virus, yields on hydrolysis amino acids equivalent to about 1 per cent of the total viral protein. The distribution of amino acids does not suggest a basic protein, although it is different from the distribution characteristic of ghost protein. This fraction has not been examined further.

These results do not exclude a possible genetic function of viral protein, but strongly suggest such a function for the viral nucleic acid.

Effects of Chloramphenicol on Nucleic Acid Synthesis

Melechen has studied the effects of chloramphenicol on the synthesis of nucleic acid in infected bacteria, as another means of assessing the role of protein in viral growth. Chloramphenicol was chosen for the following reasons.

In uninfected bacteria, this antibiotic inhibits protein synthesis, but has little or no effect on ribo- or deoxyribonucleic acid synthesis. In infected bacteria, qualitatively similar results are observed when protein synthesis is inhibited by deprivation of amino acids, or by addition of 5-methyltryptophane or chloramphenicol. These facts suggest that the action of chloramphenicol described below is due to a primary and specific effect on synthesis of protein.

Infected bacteria form protein (measured radiochemically as acid-insoluble sulfur) at the rate of 7 to 12 phage-equivalent units per bacterium per minute. Chloramphenicol reduces this rate to 10 per cent at 10 μg per ml, 5 per cent at 20 μg, and 1 per cent at 100 μg. The inhibition is established within 2 or 3 minutes after addition of the antibiotic, and is independent of time of addition.

Infected bacteria form nucleic acid at a rate that becomes linear about 10 minutes after infection, and measures 2 to 3 phage-equivalent units per bacterium per minute. If chloramphenicol is added to the culture at the time of infection, synthesis of nucleic acid and synthesis of protein are suppressed about equally. If chloramphenicol is added 10 minutes after infection, nucleic acid synthesis is scarcely affected. Additions at intermediate times yield intermediate linear rates.

These findings may be summarized by saying that nucleic acid synthesis is independent of concurrent protein synthesis, but is dependent on prior protein synthesis. Similar conclusions have been reached independently by Burton and by Tomizawa. They suggest several lines of further investigation, one of which is pursued below.

State of Phage-Precursor Nucleic Acid in the Cell

Melechen's results provide a tool for investigating the question, Does or does not the replication of viral nucleic acid occur within a virus-specific membrane?

To answer this question Melechen studied cultures of the following kind. Bacteria were infected (at 0 minutes) with phage. At 7 minutes, 10 μg per ml of chloramphenicol was added. At 45 minutes, the culture was centrifuged to remove chloramphenicol. At 60 minutes, the infected cells were returned to a culture medium that lacked chloramphenicol, causing phage growth to start. Radiochemical analysis of viral growth under these conditions revealed the following.

During the period in chloramphenicol, about 100 phage equivalents of nucleic acid were formed. Nearly all of this was incorporated into phage particles after the removal of chloramphenicol.

During the first 60 minutes, about 60 phage equivalents of protein were formed, mostly before the addition of chloramphenicol. Only 10 equivalents of this protein were incorporated into phage particles after the removal of chloramphenicol.

The first phage particles to be formed after the removal of chloramphenicol each contained about 1 per cent of the labeled viral-precursor nucleic acid. This was true whether the precursor was labeled during its formation or by infecting the cells with previously labeled phage particles. The agreement showed that nucleic acid of parental origin, and all the nucleic acid formed in the presence of chloramphenicol, shared a common pool.

Melechen interprets these results to mean that nucleic acid formed in the presence of chloramphenicol is genuine viral precursor, and that its formation requires neither synthesis of appreciable amounts of viral-precursor protein nor concurrent synthesis of protein of any kind. It follows that viral nucleic acid is not formed inside the membranes in which the finished virus particles are enclosed. It also seems likely that the specific characteristics of a molecule of virus-precursor nucleic acid do not depend on associated protein. This last point, however, calls for confirmation by genetic methods.

Viral-Precursor Protein

A systematic study of viral-precursor protein is being made, chiefly to furnish a proper background for experiments of the kind already mentioned. Detailed results will not be reported here. The chief points to emerge are the following:

1. Antigenically specific viral protein that is precursor to phage particles can be demonstrated in infected cells. The amount and rate of turnover of this protein show that it is a major precursor.

2. The time required for atoms of sulfur to pass from the sulfate in the culture medium into antigenic precursor protein (about 2.5 minutes) is similar to the time required for entry into cellular proteins in general. This shows that there is little or no nonantigenic protein that is precursor to the antigenic protein.

3. Under the conditions studied, one infected cell contains about 25 phage equivalents of precursor nucleic acid, and 13 equivalents of precursor protein. The inequality is readily explained by Melechen's experiments showing that synthesis of precursor nucleic acid can precede synthesis of precursor protein.

An Unnatural Viral Nucleic Acid

Dunn and Smith reported recently that the thymine analogue 5-bromouracil can be incorporated into the nucleic acid of T2, and that such "substituted" phage particles are noninfectious. Burgi has confirmed their results, and is attempting to locate the point at which viral function is blocked. Her preliminary results suggest that the noninfective particles attach normally to bacteria, and inject their nucleic acid. She plans to investigate the chemical and genetic consequences of this unusual situation.

Genetic Homology between Virus and Host

Many aspects of the interaction between temperate phages and their hosts can best be interpreted in terms of structural homology between the genetic materials of the two organisms. Fraser's pioneer work (Year Book No. 53) extended this concept to the virulent phage T3, and suggested that actual incorporation of host material into virus can occur. Garen, in collaboration with Norton Zinder, has now obtained radiobiological confirmation of similar ideas. The facts are as follows:

1. As measured by inactivation caused by decay of preassimilated P^{32}, or exposure to X-rays, the nucleic acids of T2 and of a temperate *Salmonella* phage are equally radiosensitive.

2. When subjected to ultraviolet irradiation, however, the nucleic acid of the *Salmonella* phage is much more resistant than that of T2.

3. When measured in terms of ability of the irradiated viruses to grow in irradiated bacteria, the sensitivity to ultraviolet light of the nucleic acid of *Salmonella* phage approaches that of T2. The radiosensitive target in the bacterium is about equal to that in the phage.

Garen and Zinder interpret these facts in the following way. Since the nucleic acid of T2 is qualitatively different from that of its host, genetic homology is excluded, and radiation damage produces a lesion that is irreparable by substitution. The nucleic acid of *Salmonella* phage is equally sensitive to primary radiochemical damage, as indicated by points (1) and (3) above. In this phage, however, ultraviolet-damaged nucleic acid can be replaced by undamaged homologous material from the host, as indicated by point (2). For some reason this substitution is not possible after P^{32} decay or X-ray damage.

This interpretation is not intended as the only possible explanation of the facts. Final proof will have to come from genetic experiments. One useful prediction is already possible. According to the interpretation made, a fundamental division among phages should be sought on the basis of nucleic acid structure, not on the basis of temperate or virulent character. The radiobiological results tend to place T2, T4, and T6 in one class and all other known phages in another.

BACTERIAL GENETICS—I

M. Demerec, P. E. Hartman, H. Moser, D. Kanazir, Z. E. Demerec, P. L. FitzGerald, S. W. Glover, E. L. Lahr, W. E. Westover, and T. Yura

Our group has continued to concentrate on analyses of the genetic constitution of the bacterium *Salmonella typhimurium,* using the transduction techniques described in last year's report. In this material we have been able to study recombination between genetic markers located within a small region of the bacterial chro-

mosome; and we have obtained evidence that a gene locus comprises a section of a chromosome, that changes occurring in different parts of this section give rise to different nonidentical alleles (pseudoalleles), and that genes associated with similar phenotypes are often closely linked. In the two cases in which both genetical and biochemical analyses have been completed, we have found that the order of such genes on a linkage map follows the same sequence as the biosynthetic reaction steps controlled by the genes. We have also made an apparently successful beginning in transformation experiments with *Salmonella,* and have continued with studies of spontaneous mutability in growing populations of *Escherichia coli.*

In addition to the workers named above, our group included Mrs. G. C. Smith, who had charge of the *Drosophila* colony; Mrs. Jean W. McIntyre, who washed and sterilized glassware; and Mrs. Emmy M. Snyder, who prepared the culture media used in bacterial experiments.

Dr. Joseph S. Gots, of the Department of Microbiology of the University of Pennsylvania, again worked with us as a guest investigator during the summer of 1955. Dr. Philip E. Hartman was with us throughout the year as a Research Fellow of the U. S. Public Health Service; and Dr. Royston C. Clowes, of the Wright-Fleming Institute of Microbiology, St. Mary's Hospital Medical School, London, arrived in June 1955 to spend a year here as a Fellow of the Damon Runyon Memorial Fund. Mr. Walter Vielmetter, of the Max-Planck-Institut für Virusforschung, Tübingen, Germany, joined our group in May 1955.

Our work received partial support from a grant-in-aid from the American Cancer Society on recommendation of the Committee on Growth of the National Research Council.

Transduction

Transduction, which was discovered by Zinder and Lederberg, is a process whereby a phage particle transfers a segment of chromosome from the bacterium in which it was grown to the bacterium which it infects. This fragment is incorporated into the corresponding chromosome of the recipient bacterium, replacing a homologous region, and so is transmitted to the descendants of that bacterium. The evidence we have obtained during the past two years indicates that this incorporation is accomplished through crossing over, that is, through an exchange of homologous parts between the chromosome strand derived from the chromosome of the recipient bacterium and the strand derived from the fragment brought in by the phage. Thus in transduction we have a mechanism for introducing a duplication of a small region of chromosome into a bacterium and for studying, by the use of appropriate genetic markers, the crossing over that occurs within the region involved. Since by this method we are able to detect classes of recombinants occurring with a frequency of about 1×10^{-8}, it is possible to analyze the genetic structure of small sections of chromosomes. Experiments using about 250 mutant characters affecting the synthesis of various amino acids, purines, and sugars (Year Book No. 53, 1953–1954, pp. 225–232) have demonstrated crossing over within gene loci in all the cases investigated. Our data indicate that a large majority of the changes responsible for independently occurring mutants associated with one gene locus originate in different parts of that locus, which can be separated by crossing over. In other words, we have observed that most alleles are nonidentical (pseudoalleles).

During the past year we have continued to analyze the genetical and biochemical properties of various groups of similar mutants in *Salmonella typhimurium,* with particular emphasis on the linkage relations among different loci. The conclusions reached will be summarized here.

Tryptophane mutants. As was mentioned in last year's report, ten tryptophane-requiring mutants were placed, as a

result of transduction tests and studies of biosynthetic blocks, in four groups (A, B, C, and D). Their sequence with respect to biochemical blocks in the chain of reactions leading to the synthesis of tryptophane is as follows:

$\xrightarrow{\;A\;}$ anthranilic acid $\xrightarrow{\;B\;}$ compound "B" $\xrightarrow{\;C\;}$

indole $\xrightarrow{\;D\;}$ tryptophane

Experiments conducted by M. Demerec in collaboration with Z. E. Demerec and Westover have shown that all four tryptophane loci are closely linked with the cystine locus *cysB*. Analysis of the frequencies of recombinant classes obtained in experiments using three or four genetic markers representing these loci has shown that the order on a linkage map of the four *try* loci in relation to the *cysB* locus is as follows: *tryD—tryC—tryB—tryA—cysB*. This linkage-map order coincides with the sequence of the biosynthetic blocks associated with the *try* loci.

Histidine mutants. Data obtained by Hartman from a biochemical survey and from transduction tests with 34 histidine mutants have demonstrated a complex genetic structure, which is interpreted as involving three levels of genetical organization: (1) nonidentical alleles within each locus, (2) at least four gene loci, and (3) a clustering of these loci representing a common primary phenotype.

In the biochemical survey, imidazole derivatives were tentatively identified by paper chromatography and chemical tests (methods of Ames and Mitchell) of crude supernatants and eluates from chromatograms. The reactions studied were: accumulation of imidazoles, biochemical transformation by cell suspension, cross feeding, and growth on known imidazole derivatives. On the basis of these criteria the mutants were placed in four groups, A to D. Group A was composed of strains *hi-3, -5, -6, -11, -30, -32, -33, -35, -38, -25,* and *-26;* group B included *hi-12, -14, -20, -21, -22, -24,* and *-29;* group C mutants were *hi-2, -8, -13, -15, -28,* and *-31;* group D was composed of *hi-1, -9, -10, -17, -18, -23, -27, -34, -36,* and *-37*. The members of each group appeared to have in common a genetic block affecting a single reaction step in a primary pathway of L-histidine synthesis (see fig. 1). In addition, the data indicated that a shunt, of secondary metabolic importance, branched off from the primary pathway but led to the same end product, L-histidine.

In the genetic survey, each mutant strain was transduced with phage grown on each of the mutants and plated on medium lacking histidine, for the recovery of prototrophic recombinants. The numbers of wild-type colonies recovered formed an imperfect but nearly continuous range, beginning with zero. The numbers were always *less* than when phage grown on wild-type bacteria was used in the transduction. These results indicated that all the mutant markers were linked to one another and that, in general, linkage was closest between mutants that were biochemically homologous.

Mutant strain *hi-32* has a unique ability to grow on purines as well as on L-histidine. This ability was demonstrated to be an inherent property of the *hi-32* allele, inseparable by transduction. When other histidine mutants were transduced with phage grown on *hi-32* and plated on medium supplemented with purines, there appeared large colonies representing the wild-type genotype and small colonies representing the genotype of *hi-32*. The genotype of the small colonies was tested by their behavior in transduction experiments with phage grown on the parental and *hi-32* strains, by their alternate growth requirements, and by their accumulations. The results demonstrated that the small-colony cells carried the *hi-32* allele, brought into the recipient bacterium by the phage, but no longer possessed the histidine marker originally present in the bacteria; that is, they were the consequence of simultaneous or linked transductions. Similarly, small colo-

nies arising from transduction of histidinol-accumulating group-D strains by phage grown on group-A, -B, or -C strains were found to have the genotype and phenotype of the strain on which the phage was prepared. Bacteria constituting the small colonies were able to grow on the histidinol excreted by residual background group-D cells. The frequency of occurrence of single transductions, leading to wild-type colonies, was compared with that of linked transductions, leading to mutant colonies characteristic of the donor bacteria.

Figure 1 illustrates the approximate positions of the mutant markers on a linkage map, and the apparent positions of their genetic blocks in the primary pathway (solid arrows) of L-histidine synthesis. Postulated biochemical side reactions are indicated by dotted arrows.

Each of the four histidine gene loci appears to be a complex element, comprising a discrete unit or length of the bacterial genome (chromosome) and concerned with a single, dispensable, primary function, probably the production of a specific

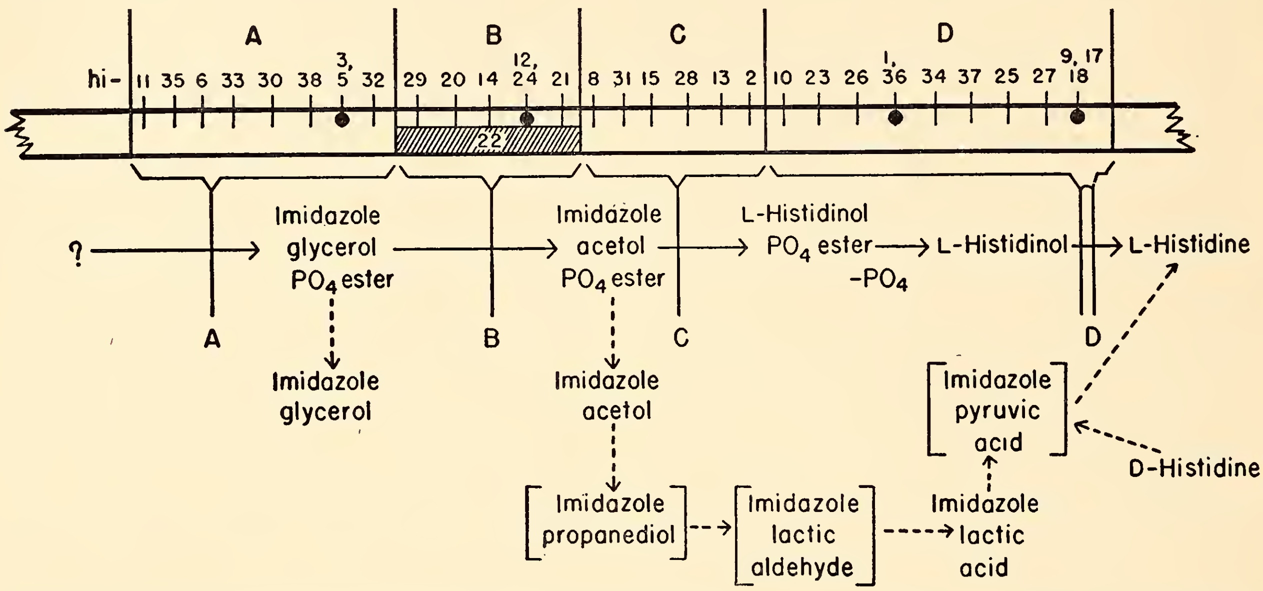

FIG. 1. Linkage map and proposed biochemical sequences for L-histidine synthesis in *Salmonella typhimurium*.

The initial results obtained by the method of reciprocal transduction, in which only wild-type colonies were recovered, were confirmed and extended by the more accurate method involving simultaneous recovery of two different recombinant classes as large and small colonies. The combined results clearly show that all the mutants are closely linked. Their placement on a linkage map corresponds strikingly to their grouping by biochemical tests. The only two exceptions, *hi-25* and *-26* of region D, have irreversible, aberrant adenine blocks as the result of second, independent mutations; their failure to be placed in group D biochemically can be attributed to their slow growth because of the adenine block.

enzyme. The sequence of the loci on the linkage map parallels the sequence of biochemical reactions in the primary pathway of L-histidine synthesis.

Results of the experiments show that mutation may occur at a number of sites within each of the loci; that is, most of the mutant markers at any single locus may be differentiated from one another by recombination during transduction. Several pairs, however (indicated in fig. 1 by circles), do not recombine with each other. Of these, *hi-3* and *-5*, and *hi-17* and *-18*, may represent two cases of independent isolation of progeny resulting from a single mutational event. Mutant *hi-12* is distinguished from *hi-24*, and *hi-9* from *hi-17*

and *-18,* on the basis of their behavior in transductions with other mutants; *hi-9* also differs from *hi-17* and *-18* in rates of spontaneous and ultraviolet-induced mutation to prototrophy. The members of one pair, *hi-1* and *-36,* are identical by the three criteria applied.

The mutant *hi-22,* whether used as recipient or as donor, gives no transductions to wild type with other members of group B. Certain mutant alleles of each group, and most strikingly *hi-22,* appear to suppress (or, in some cases, enhance) the frequency of recombination with other markers.

The histidine group of loci is not demonstrably linked with markers representing 23 loci involving other nutritional functions.

Methionine mutants. Using transduction techniques, Glover has made a study of allelism among 32 methionine-requiring strains. The results are similar to those reported last year for mutants requiring other amino acids. The transduction tests showed that these methionine mutants could be divided into five groups, according to the frequency of transductions observed when bacteria of one group were infected with phage raised on bacteria belonging to another group. In tests between members of the same group the number of transductions was considerably smaller than in experiments involving members of different groups or when phage raised on wild-type bacteria was used. Fourteen of the mutants belong to group A, 11 to group B, 5 to group C, 1 to group E, and 1 to group F.

The mutants were tested for cross feeding by streaking them in combinations of two on minimal agar plates slightly enriched with broth, and also by plating mixtures of pairs of mutants in proportions such that one would form a background growth on the surface of the minimal agar and might or might not feed the small number of cells of the other mutant present in the mixture. The results of these two sets of experiments are in agreement, and show that the members of group A are unable to feed any of the other mutants, the members of group B feed the group-A mutants, group-C mutants feed groups A and B, groups E and F feed groups A, B, and C, and groups E and F show no cross feeding. These findings indicate that the members of a particular transduction group exhibit similar cross-feeding relationships and, further, that the groups can be arranged in the following order to show the sequence of the blocks they represent in the pathway of methionine synthesis: A—B—C—(EF)—L-methionine.

Compounds suspected of being intermediates in the pathway of methionine synthesis were incorporated into minimal medium, on which the mutants were streaked to test their growth responses. Groups E and F, which could not be separated on the basis of the feeding experiments, could be distinguished by their different responses to vitamin B_{12}. Groups A and B, however, which were differentiated by the fact that B feeds A, were not distinguishable in their growth responses to methionine precursors. These results are consistent with the following arrangement of the biochemical blocks:

$$\begin{array}{c} \text{L-cysteine} \\ + \\ \text{homoserine} \end{array} \xrightarrow{\ \ A\ |\ \ B\ |\ } \text{cystathionine} \xrightarrow{\ C\ |\ }$$

$$\text{homocysteine} \xrightarrow[\substack{\uparrow \\ B_{12} \\ E\text{—}\uparrow\text{—}}]{F\ |} \text{L-methionine}$$

The fact that group-B mutants are able to feed group-A mutants implies that the condensation of L-cysteine and homoserine to form cystathionine may proceed by two steps, and there is evidence from work with *Neurospora* that this may well be the case.

A number of strains used in this study carried in addition to the methionine requirement another deficiency resulting from an additional single-step mutation.

Such double-mutant strains are especially well suited for the study of linkage relations. In cases where linkage between several markers is indicated, double-mutant strains can be used in three- and four-point tests to determine the order of linkage. In tests of this sort it was found that all the methionine loci are linked with one another and also with the cystine and tryptophane loci. The combined results of our studies of linkage relations in this group of loci indicate that their order on a linkage map is as follows: *tryD—tryC—tryB—tryA—cysB—meE—cysA—meC—meA—meB—meF—* $\frac{cysC}{cysD}$.

Cystine mutants. Forty-four cystine-requiring mutants have been placed in four groups by studies of transduction frequencies and nutritional requirements conducted by Zlata Demerec. Group A contains 8 mutants; group B, 21; group C, 4; and group D, 11. Tests with Na_2SO_3 and $Na_2S_2O_3$ showed that the deficiency can be satisfied in group-A mutants by Na_2SO_3, in group-D mutants by $Na_2S_2O_3$, in group C by either of these two compounds, and in group B by neither. Tests made with all the mutants revealed no cross feeding. The deficiency in all but one mutant of group A, and in a few mutants of each of the other three groups, can be partially satisfied by either methionine, homocysteine, or cystathionine. The assumption that the partially satisfied mutants are so-called "leaky" mutants would explain this observation.

The four cystine loci are sufficiently close to the four tryptophane and five methionine loci to be included with some of them in a single transducing fragment and thus show linkage in transduction experiments. As indicated in the previous section, *cysB* is preceded on the linkage map by the four tryptophane loci, and followed by *meE, cysA,* four other methionine loci, *cysC,* and *cysD.*

Proline mutants. Previous experiments with 16 proline-requiring mutants indicated that they belonged to two transduction groups, one containing 15 mutants and the other 1. During the past year Kanazir continued the analysis of these *pro* mutants, concentrating on biochemical aspects of the problem. Growth-response experiments and cross-feeding tests discriminated among the 15 members of the larger transduction group, dividing it into two parts and placing the 16 *pro* mutants in three groups, designated A (1 mutant), B (11 mutants), and C (4 mutants). Results of the growth-response experiments are summarized in table 1. The cross-feeding tests showed that the group-A mutant feeds the group-B mutants but revealed no cross feeding between mutants of group C and any of those belonging to groups A and B.

TABLE 1

Summary of the results of growth-response experiments dividing 16 proline-requiring mutants into three groups (A, B, C)

Medium	A	B	C
Proline	+	+	slow
Glutamic acid	..	..	..
Glutamic-γ-semialdehyde	..	+	slow
Ornithine	..	slow	slow

Further tests showed that the group-A mutant accumulates a compound which has been identified—by its yellow color with O-aminobenzaldehyde, by its maximum of absorption at 430 mμ (pH 7), and by chromatographic comparison with the synthetic compound (kindly supplied by Dr. F. H. Vogel, of Yale University)—as glutamic-γ-semialdehyde or its cyclized derivative Δ^1-pyrroline-5-carboxylic acid. The group-A mutant also accumulates, in high concentration, a compound which, extracted according to Friedmann, produces a specific reaction with 2,4-dinitrophenylhydrazine, and whose spectrum of absorption is shown in figure 2. Accumulation of this compound was not observed with either wild-type bacteria or group-C mutants. Group-B mutants accumulate the compound, but its concentration in the

medium is about one-half that found with the group-A mutant. Chromatographic analysis showed that this compound produces a spot with an Rf similar to that of the hydrazone derivatives of α-ketoglutaric acid. The spectrum of the compound is similar to the spectrum of 2,4-dinitrophenylhydrazones of α-ketoglutaric acid. The group-B mutants also accumulate glutamic acid. These mutants are able to convert exogenous ornithine into proline, and the use of ornithine as the single source of carbon indicates that this conversion probably proceeds through glutamic-γ-semialdehyde; that is, it follows

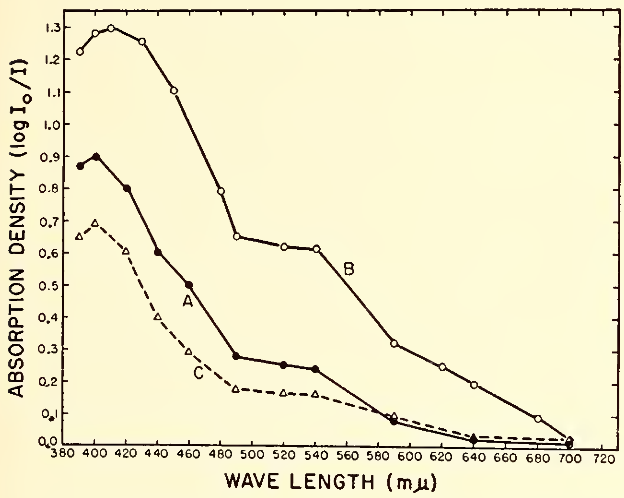

FIG. 2. Absorption spectrum of 2,4-dinitrophenylhydrazones of compound accumulated in medium by mutants. *A,* 2,4-dinitrophenylhydrazones of α-ketoglutaric acid (control); *B,* 2,4-dinitrophenylhydrazones of accumulated compound (extraction according to Friedmann); *C,* 2,4-dinitrophenylhydrazones of same compound isolated by paper chromatography.

the same pathway as that described by Vogel in *Escherichia coli* and *Neurospora crassa.* Analysis of the group-C mutants has not progressed far enough to indicate their position in the pathway of biosynthetic reactions.

The data available at present indicate that the path of proline synthesis in *Salmonella* involves the following steps: glutamic acid → glutamic-γ-semialdehyde → Δ^1-pyrroline-5-carboxylic acid → proline; and that the biochemical block is between glutamic-γ-semialdehyde and proline in the case of the group-A mutant and between glutamic acid and glutamic-γ-semialdehyde in the group-B mutants.

Information obtained from study of the group-B and -C mutants, although not yet complete, suggests that glutamic-γ-semialdehyde, ornithine, and proline present a closely related biochemical system. Utilization of ornithine as the single source of carbon by group-B mutants supports Vogel's finding that exogenous ornithine is used via glutamic-γ-semialdehyde in the synthesis of proline. The finding that mutants of groups A and B are able to oxidize proline indicates that the enzyme system involved in oxidation is similar to that involved in proline synthesis. Our information is not yet adequate to support the view that this is a reversible reaction.

Results of the transduction experiments indicate that the mutants of groups B and C are closely linked.

Leucine, isoleucine, and valine mutants. Mutants requiring the branched-chain amino acids, valine, isoleucine, and leucine, have been studied by FitzGerald, using transduction and biochemical techniques to determine their genetic behavior and biosynthetic pathways. On the basis of nutritional requirements, these independently isolated mutants can be divided into three classes: leucine (14), isoleucine (3), and isoleucine-valine (5).

Reciprocal transductions were carried out among all 14 leucine (*leu*) mutants. The frequency of occurrence of transduction to wild type among *leu* mutants was always lower than that between *leu* and the wild type or between *leu* and *me*, indicating linkage among these mutants. There seemed to be two subgroups with low intragroup frequencies, and several mutants showing intermediate frequencies of transduction with members of both these groups. Feeding tests indicated that none of the *leu* mutants feed each other. Isoleucine and isoleucine-valine mutants do not feed the leucine group. Growth tests for utilization of possible intermedi-

ates, made by the auxanographic method, were positive for α-ketoisocaproic acid, the direct precursor of leucine. None of the other postulated intermediates was utilized, including α-ketoisovaleric acid and valine. It seems, therefore, that this group is blocked in the conversion of α-ketoisovaleric acid into α-ketoisocaproic acid. If the block occurred before this step, the mutants would require valine and would be able to convert it to leucine. This statement is based on the assumption that the pathway of leucine synthesis is similar to that in *Escherichia coli.* Since no mutants blocked in the transamination of the keto acid to leucine were found, it also seems reasonable to assume that *Salmonella,* like *E. coli,* may have more than one transaminase capable of catalyzing this reaction.

There is so far no direct evidence concerning the mechanism of the conversion of α-ketoisovaleric acid into α-ketoisocaproic acid. Data from tracer experiments are consistent with the hypothesis that α-ketoisovaleric acid is decarboxylated and subsequently condenses with a two-carbon fragment to form α-ketoisocaproic acid. Until the number of steps involved is known, however, it is not possible to correlate the biochemical with the transduction results. Although the latter seem to indicate two groups of *leu* mutants, the transduction frequencies do not differ enough to denote a clear-cut separation.

Transductions to wild type among the 3 isoleucine (*isl*) and 5 isoleucine-valine (*isva*) mutants and between these and wild-type, *leu,* and *me* strains indicate that the *isl* mutants are more closely linked to one another than to the *isva* mutants. The latter form two groups, one (A) containing 4 strains and the other (B) 1 strain. The frequency of transduction between *isvaA* and *isvaB* is much higher than that between *isvaA* and *isl,* and that between *isvaB* and *isl* is still higher. There is no evidence of linkage between *isl* or *isva* and the *me* strain tested. Transduction of *isl* and *isva* by a *leu* strain, however, is about half as frequent as their transduction by the wild type, indicating some linkage with *leu.*

There is no feeding among the *isl* or among the *isva* mutants. The *isl* mutants are fed by the *isva* and *leu* mutants—an indication that the biosynthetic block represented by *isl* occurs at an earlier stage. This is to be expected, since the double requirement for isoleucine and valine arises because common enzymes are involved in the last steps in the syntheses of these two amino acids, that is, in the conversion of the dihydroxy acid into the α-keto acid, and of the latter into the amino acid. The block in *isvaB* occurs before the dihydroxy acid, and that in *isvaA* between the dihydroxy and the α-keto acids, since the former group will grow either on both dihydroxy acid precursors or both α-keto acid precursors of isoleucine and valine, whereas the latter group will grow only on the two α-keto acids. The lack of mutants blocked at the transamination step may be explained, as in the *leu* group, by the possible existence of more than one enzyme capable of transaminating isoleucine and valine.

The three *isl* mutants, like some described in strain K-12 of *E. coli,* will grow well on L-isoleucine, α-keto acid, and α-aminobutyric acid, not so well on D-threonine, and not at all on L-threonine. They also grow, as expected, on α,β-dihydroxy-β-methylvaleric acid and α-keto-β-methylvaleric acid, the direct precursors of isoleucine. In these strains, L-threonine inhibits the utilization of D-threonine but not of isoleucine. They may be incompletely blocked in the ability to racemize D- and L-threonine, but the exact nature of the block remains to be determined. Neither serine nor homoserine inhibits the utilization of D-threonine or isoleucine, as they have been observed to do in some D-threonine strains of *E. coli* (G. Cohen). Instead, serine enhances the utilization of D-threonine by the *isl* mutants of *Salmonella.*

None of the other postulated intermediates in the synthesis of the branched-

chain amino acids supported growth. These were pyruvic acid, L-aspartic acid, L-lysine, L-alanine, L-methionine, and DL-homoserine.

Growth studies of the *isva* mutants, using varying amounts of the two amino acids, showed that in the presence of excess valine the rate and the total amount of growth were functions of the isoleucine concentration, whereas in the presence of excess isoleucine, growth—and so presumably the utilization of valine—was inhibited until the concentration of valine approached that of isoleucine. This inhibition is probably a result of competition, in the last two steps in the synthesis of isoleucine and valine, for one or both of their common enzymes.

Accumulation tests should be carried out to determine where the block occurs in the *isl* mutants and to establish whether the *leu* mutants comprise one or more groups. More direct proof is needed to establish the conversion of α-ketoisovaleric acid into α-ketoisocaproic acid, and the nature of the steps involved, since no intermediate has yet been identified.

Serine mutants. Tests with 26 serine mutants of independent origin, conducted by Zlata Demerec, have shown that they fall into two distinct transduction groups, one containing 25 mutants and the other 1 mutant. There is no evidence of linkage between the two groups. In experiments carried on by Vielmetter, cross feeding was not detected between any of the serine mutants. He found that in all of them the serine deficiency can be partially satisfied by threonine, that is, they grow slowly on minimal medium to which threonine has been added. He was unable to detect any accumulation of α-keto acids.

Results of these studies indicate that at least two gene loci controlling the synthesis of serine are represented in our material, and that they are not located sufficiently close to each other on the chromosome to be included together in a transducing fragment—not, at any rate, with a frequency that could be detected in our experiments.

Purine mutants. Studies of purine-requiring mutants have been continued by Yura. They have included 12 adenine-thiamine strains isolated independently as single-step mutants from the wild type LT2, as well as 12 adenine mutants partially investigated last year. On the basis of the biochemical analysis reported last year, and of further transduction tests using lysogenic derivatives of these strains, the 12 adenine mutants have been assigned to four groups (*adA* to *adD*). Tentative locations of the genetic blocks involved in the requirements of these mutants are indicated in figure 3. So far, efforts to differentiate between *adA* and *adB* by biochemical methods have not been successful.

All 12 adenine-thiamine mutants are nonspecific in their requirement for purines, growing on adenine, hypoxanthine, guanine, or xanthine in the presence of thiamine. Growth is also supported, in all the mutants except *ath-6,* by 5-amino-4-imidazole carboxamide (AICA) plus thiamine. Pantothenate can replace the thiamine part of the requirement to various degrees, depending on the strain. Gots and Yura showed that *ath-6* accumulates an arylamine indistinguishable from AICA. No specific accumulation could be demonstrated for the other mutants, and these mutants have been tentatively assigned a block, or blocks, at a very early level involving precyclization processes. Transduction tests placed the 12 mutants in three groups; and one of these (*ath-6, -11,* and *-12*) was divided into two on the basis of biochemical tests, thus making four groups (*athA* to *athD,* fig. 3).

The differences observable among the mutants of the *athA* group in growth response to adenine-pantothenate medium made it possible to detect types produced by double transduction between members of this group, thus affording direct evidence of close linkage within a group. Strains not capable of growing on adenine-pantothenate agar were infected with

phage from strains capable of growing on that medium, then plated on minimal and on adenine-pantothenate agar. Only prototrophs (resulting from single transduction involving the recipient marker) appeared on the minimal plates, whereas bacteria of the donor type (double transduction, involving both the recipient and the donor markers) as well as prototrophs appeared on the adenine-pantothenate plates. The single transductions produced large colonies, whereas the colonies resulting from double transductions were small and could readily be distinguished from the large ones. Calculations of the relative distances between alleles, based on ratios of single to double transductions, showed a reasonable consistency, and formed the basis for a preliminary mapping of the mutants in linear order.

Frequencies of spontaneous and ultraviolet-induced reversion of all the mutants were determined. In four sets of mutants, within each of which no transduction to prototrophy occurred, there were also no significant differences among members of a set as to frequencies of spontaneous or ultraviolet-induced reversion, a fact which suggests that the members of each set may be identical alleles. In some cases, the mutant frequencies were found to be different among members of the same transduction group, an indication that the types of genetic change resulting in biochemically similar mutants may be different in the various mutants. Mutant *ad-3,* which cannot be transduced to prototrophy by phage from wild-type bacteria or from any mutant tested, underwent no reversion. Mutant *athA-10,* not transducible to prototrophy with other members of the *athA* group but transducible with mutants of other groups, also failed to show any reversion. These results favor the assumption that mutations to *ad-3* and *athA-10* are complex.

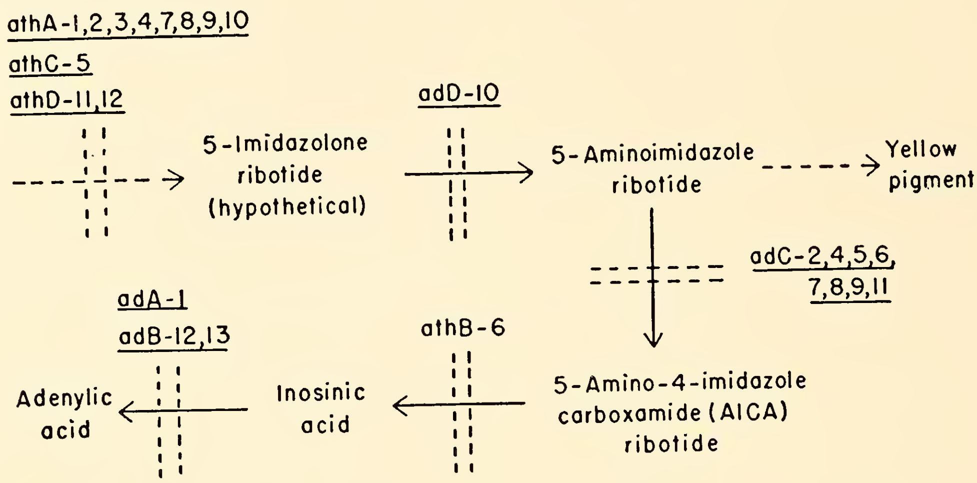

FIG. 3. Tentative diagram of the pathway of purine synthesis in *Salmonella typhimurium.* Arrows indicate the direction of synthesis. Dotted double lines represent genetic blocks.

The mechanism of suppressor mutations was studied by Gots in a "revertant" of the purine-requiring mutant *ad-11.* The *ad-11* requirement apparently results from a block in the conversion of 5-aminoimidazole riboside (AIR) to the corresponding riboside of 5-amino-4-imidazole carboxamide (AICA), since the mutant accumulates AIR and can use AICA for growth. A prototrophic "revertant" of this mutant was isolated by Yura and shown by him to be the result of a suppressor mutation; that is, the loss of the purine requirement was due not to a back-mutation of the *ad-11* gene, but to mutation at another locus. This suppressor mutant, *ad-11 s,* differs from the wild type in its slower rate of growth in the absence of purines, and it continues to accumulate AIR. Several explanations may be considered. The

presence of the suppressor gene in the wild type may have a regulatory function which suppresses a secondary, less economical, pathway of purine synthesis. A loss of this function would allow the secondary pathway to operate, thus relieving the purine requirement but not the accumulation of the originally blocked substrate. On the other hand, the suppressor mutation may function to open up the originally blocked reaction. The evidence obtained by Gots supports the latter hypothesis.

The experimental approach was to measure the ability of the suppressor mutant to synthesize the product of the blocked reaction, that is, AICA. This was done in two ways: (1) Sulfonamide blocks the conversion of AICA, and therefore the synthesis of AICA can be measured under conditions of sulfonamide bacteriostasis. (2) Cell-free extracts of the bacteria can synthesize purine intermediates under conditions worked out by Gots and Gollub (unpublished) with mutants of *E. coli*.

1. Like other bacteria, the wild-type *Salmonella* strain used here will accumulate AICA when subjected to sulfonamide bacteriostasis. Organisms with genetic blocks before AICA were shown to be unable to accumulate AICA, an indication of inability to synthesize this intermediate. Under conditions of sulfonamide bacteriostasis the suppressor mutant *ad-11 s* behaved very much like the wild type with respect to AICA synthesis. Thus, the suppressor mutation allows the conversion of AIR to AICA, a reaction which cannot be performed by the original *ad-11* mutant.

2. It can be shown that cell-free extracts of mutants which are blocked in the conversion of AICA synthesize AICA. Cell-free extracts were prepared here by grinding with alumina according to the method of Englesberg. Total synthesis can be obtained with only four ingredients: ribose-5-phosphate, glutamine, phosphoglyceric acid, and adenosine triphosphate. Cell-free extracts of *ad-11* cannot synthesize AICA, but rapidly synthesize its immediate precursor, AIR. Cell-free extracts of the suppressor mutant *ad-11 s* show an unequivocal synthesis of a mixture of AIR and AICA. Thus, the suppressor mutant does contain the enzymes necessary for the conversion of AIR to AICA.

General conclusions. Two significant features have emerged from our experiments with transduction in *Salmonella*. One is the finding that by means of transduction techniques it is possible to analyze, with a great deal of precision, the genetic structure of short regions of the bacterial chromosome; and the second is the discovery, as a result of such analysis, that in our material the order of loci on the chromosome apparently follows a very unusual pattern.

The length of the chromosomal region that can efficiently be studied in any one experiment is determined by the length of the fragment transported by the infecting phage. Our experience indicates that in *S. typhimurium* these fragments are very short in relation to the total chromosome length, but that they can include several loci. In experiments with the *try—cys—me* region of the chromosome, we have been able to recognize fragments including as many as twelve identified gene loci. In such cases, however, the markers located at either end of the region very seldom participated simultaneously in transduction, a fact which suggests that the length of the section between them is close to the maximal length of fragment that can be transferred by a phage particle, at least in this particular region of the chromosome.

Our linkage studies have shown that loci associated with related metabolic functions—for example, steps in the synthesis of tryptophane, or of histidine, methionine, adenine, adenine-thiamine, proline, leucine, isoleucine, or isoleucine-valine—are not distributed at random along a chromosome, but are closely linked. In the case of loci associated with tryptophane and histidine synthesis, which have been analyzed more exhaustively than others, the available evidence indicates that four trypto-

phane loci, and also four histidine loci, are adjacent to one another and, moreover, that their order on a linkage map coincides with their sequence in respect to biochemical blocks in the chains of reaction leading to the synthesis of tryptophane and histidine, respectively. Correspondence between linkage order and biosynthetic sequence is also suggested by results of experiments, not yet completed, with adenine, adenine-thiamine, methionine, isoleucine, and isoleucine-valine mutants; that is, in almost every case in which we have available for analysis several loci associated with related metabolic functions. This indicates that such nonrandom gene arrangements must be common in *Salmonella.* That such an arrangement is not obligatory, however, is shown by the finding that the *cysB* and *cysC* loci, although linked, are separated by a block of *me* loci.

The discovery of nonrandom gene arrangement is the most unexpected result of our studies. There is sufficient evidence to show that it is not present, in the form observed in *Salmonella,* either in fungi or in other higher organisms. For example, it is known that in *Neurospora* four tryptophane loci, corresponding to our four loci in *Salmonella,* are in different linkage groups, and presumably in different chromosomes.

So we are faced with the question of how to interpret the occurrence of nonrandom gene arrangements, and the fact that they are found in *Salmonella* (presumably in all bacteria) but not in higher organisms. The answer to the first part of this question is evident if one assumes that the close linkage among genes associated with similar phenotypes, and the correspondence between linkage order and biosynthetic sequence, are advantageous to the organism. On this basis one would expect certain gene arrangements having selective advantage to be developed during a long series of evolutionary readjustments, regardless of the nature of origin of the genes involved, or their original positions on the chromosome.

It is easy to visualize conditions which in the course of evolution would bring about the kind of nonrandom gene arrangements revealed by our experiments. For example, it is possible that several genes take part in a chain reaction, each controlling a certain single step, and that either the production of the substance essential for each reaction step proceeds at a low rate or the substance itself is labile or nondiffusible. In these circumstances, proximity of such genes to one another and a particular sequence of arrangement on the chromosome would result in more efficient functioning, or might even under certain conditions be essential for the occurrence of a reaction. In this case, the difference between *Salmonella,* where a nonrandom gene arrangement has been found, and higher organisms, where it has not been found, might be due to a difference in rate of reaction. It may well be that this rate is lower in bacteria, either because of smaller cell size or because of differences in chromosome organization.

Another way of explaining the observed difference between bacteria and other groups of organisms is by assuming that in bacteria the nucleus is the site of metabolism and that all metabolic reactions are carried on by the genes themselves, whereas in higher organisms these reactions are performed by certain organelles in the cytosome. In this case, if proximity and sequence are important for the performance of interrelated reactions, they may be brought about in bacteria by adjustment of the arrangement of genes on a chromosome, whereas in other organisms they may be achieved through the action of some other forces operating in the cytosome.

Transformation

It has been known for some time that deoxyribonucleic acid (DNA) extracted from a strain of bacteria is able to transfer certain genetic characters of that (donor) strain to another (recipient) strain. This can be mediated simply by

bringing the DNA into contact with bacteria of the recipient strain. Transformation was first discovered in pneumococcus, and has recently been detected in several other bacterial species. Recent studies by Dr. Rollin D. Hotchkiss, of the Rockefeller Institute, have shown that two particular genetic markers are transformed simultaneously with a frequency considerably higher than the random expectation. This suggests a linkage relation, on the supposition (1) that the DNA constitutes a portion of the genetic material of the donor bacteria and (2) that these two markers are located close enough together on a bacterial chromosome so that both are frequently included in a single DNA thread.

It is evident that if transformation is effected by means of the mechanism suggested by Hotchkiss' results, it will be a valuable tool in extending our studies of the genetic structure of the bacterial chromosome, now being conducted by transduction methods. Therefore Lahr, in collaboration with Demerec, has begun a series of experiments with strain LT2 of *Salmonella typhimurium,* in order to find out whether or not transformation can be induced in that strain of bacteria, and, if possible, to use this method in a further analysis of the genetic markers already studied by transduction procedures. We report here the first results of these experiments.

We have succeeded in bringing about transformation, that is, the transfer of genetic markers from donor to recipient bacteria, using either disintegrated bacteria or DNA extracted from such bacteria by a process similar to that employed in work with pneumococcus. We have observed, in the case of the genetic markers studied so far, that the frequency of transformation, with either of the donor materials but particularly with DNA, is at least as high as the frequency of transduction in experiments carried on with the same genetic markers and under optimal conditions. We have found that donor material consisting of disintegrated bacteria, which has been used effectively to induce transformation, loses its potency after treatment with deoxyribonuclease, as would be expected if DNA is responsible for its effectiveness.

Up to now we have carried out experiments with markers representing the *tryD* and *cysB* loci, since this region of the chromosome has been thoroughly analyzed by transduction techniques. The results show that, in a great majority of cases, mutation has occurred at loci in proximity to the marker locus being used to detect transformations. In all our experiments the wild-type strain has been used in preparing the donor material. When the recipient bacteria carried a *tryD* marker, most of the transformants, detected on the basis that they were $tryD^+$, were also either *tryC, tryB,* or *tryA.* These results indicate that during the process of extracting the DNA-containing material from donor bacteria, changes were induced in the genetic material, and that these were transmitted to the offspring of the recipient bacteria; in other words, that we have been able to induce mutations in vitro.

Mutability in Growing Bacteria

Data reported by Moser last year indicated that under certain conditions the hourly rate of mutation from T5 sensitivity to T5 resistance in B strains of *Escherichia coli* becomes a function of growth rate. During the past year he has carried out a series of experiments to investigate this phenomenon more precisely. Two derivatives of strain B/r were analyzed, one requiring histidine (*hi-5*) and the other also giving rise to fast growth at low concentrations of NH_4Cl (*hi-5, f*). Populations of strain B/r *hi-5* were maintained in the chemostat at 37° C at generation times τ ($\tau=0.693/\omega$; $\omega=$hourly wash-out rate per ml of culture) ranging from 347 minutes to 67 minutes. Friedlein's lactate medium was used as input nutrient, with NH_4Cl as the controlling

growth factor. In all experiments, curved lines were obtained when the frequency of mutants resistant to phage T5 was plotted against time; and every curve was consistent with the mathematical prediction for adverse selection (see Year Book No. 53, p. 238). Figure 4 illustrates an example in which the T5-resistant mutants approached exponentially a selection-mutation equilibrium which was found by trial to be attained at a maximum mutant frequency of 140 per 10^8 cells. In the semilogarithmic plot of $\Delta f = 140 \times 10^{-8} - f$ against time t, a straight line was obtained in accordance with expectation ($\lambda \ll sW/V$),

$$^{10}\mathrm{Log}(\tilde{f}-f) = -0.4343 \times \frac{sW}{V} \times t + {}^{10}\mathrm{Log}(\tilde{f}-f_0).$$

(W, hourly flow rate; V, culture volume; f_0, initial mutant frequency; s, selection coefficient; $\tilde{f}$, maximum mutant frequency.) Since s was known from the logarithmic slope, the hourly mutation rate λ could be calculated in each case in accordance with the formula $\lambda = \tilde{f}sW/V$.

Different selection coefficients were obtained for the T5-resistant mutants if the parent strain was grown at different generation times, but these variations did not parallel those of the mutation rate (see table 2). At generation times between 90 minutes and 150 minutes, selection against the mutant varied erratically between 2.5 per cent and 4.5 per cent, but it seemed to increase below $\tau = 90$ minutes and above $\tau = 150$ minutes.

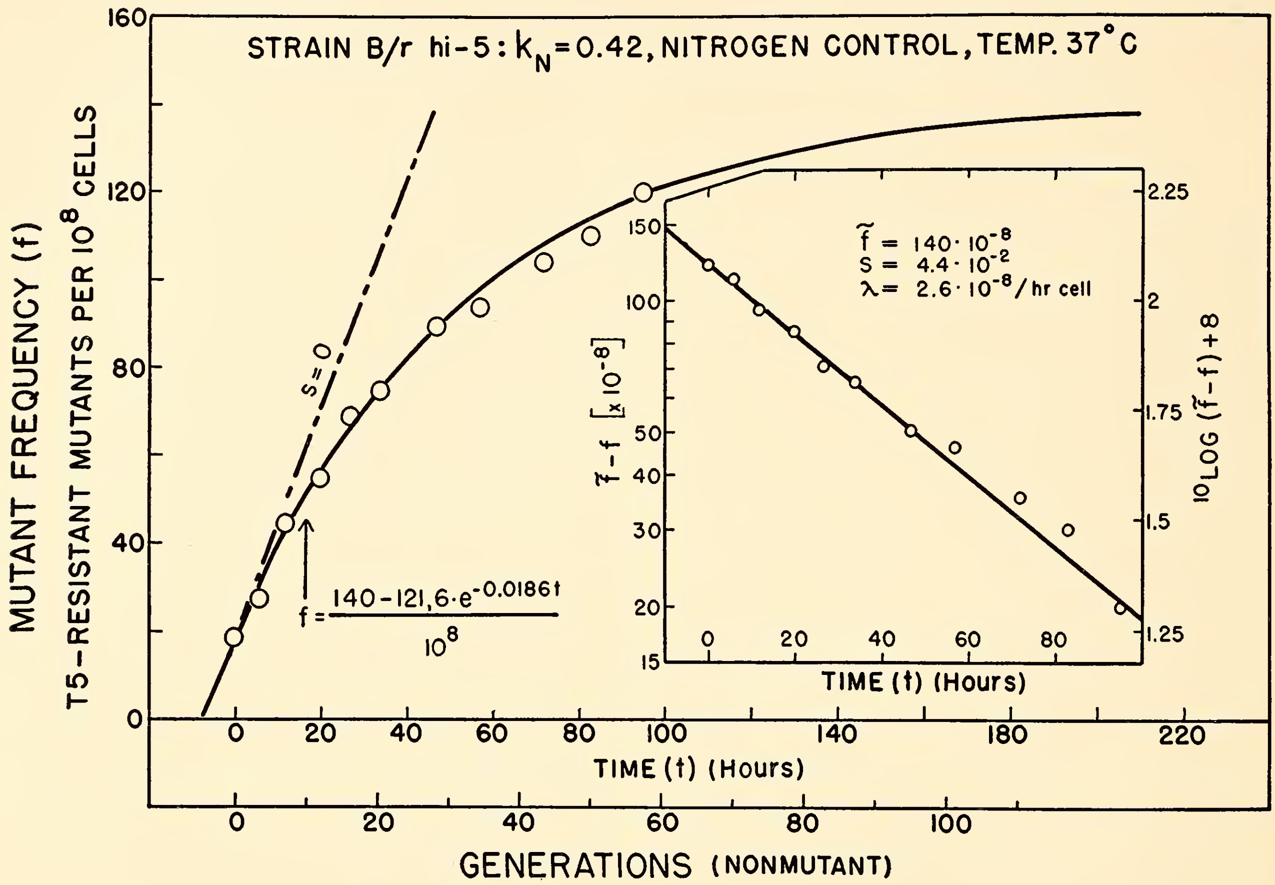

FIG. 4. Accumulation of T5-resistant mutants in strain B/r *hi-5* grown at a generation time of 99 minutes in histidine-supplemented lactate medium with 30 mg/l NH_4Cl input.

The hourly rate per cell of mutation from T5 sensitivity to T5 resistance remained constant, at a value of 1.6×10^{-8}, between generation times of 350 and 120 minutes, but increased significantly with shorter generation times, reaching a value of about 4×10^{-8} at 67 minutes. It is of interest to note that in this range of τ the

spontaneous-mutation rate per time unit and per cell appeared to increase proportionally with growth rate.

The data presented in table 2 indicate a possible relation between spontaneous-mutation rate and cell metabolism. The fact that cell density $\tilde{n}$ did not drop continuously with increasing growth rate shows that the concentration $\tilde{c}$ of NH_4Cl in the growth tube remained negligibly small in comparison with the input concentration a (=30 mg NH_4Cl/l). Therefore q, that is, the amount of limiting growth factor (ammonium chloride in our case) taken up per bacterium produced, could be estimated according to Novick and Szilard's approximation formula, $q=a/\tilde{n}$. The data show that the amount of limiting nutrient assimilated per bacterium and bacterial life span remained constant at the longer generation times up to about $\tau=90$ minutes. Below this generation time, however, q began to increase abruptly as the generation time became shorter, paralleling the observed increase in spontaneous-mutation rate.

As a by-product of these studies, it was found that the rate of mutation to T5 resistance, at a given growth rate, may differ—particularly at the shorter generation times—in different *f* strains derived from the same strain of B/r *hi-5* (table 3).

TABLE 2

DATA OF CHEMOSTAT EXPERIMENTS WITH A HISTIDINE-REQUIRING DERIVATIVE (*hi-5*) OF STRAIN B/R OF E. COLI, MEASURING RATES OF MUTATION FROM SENSITIVITY TO RESISTANCE TO PHAGE T5

(F medium; 37° C; controlling growth factor, NH_4Cl [30 mg/l]; supplement, D,L-histidine HCl [20 mg/l])

Generation time τ (min.)	Cell density $\tilde{n}$ ($\times 10^8$/ml)	NH_4Cl uptake q ($\times 10^{-14}$ g/bacterium produced)	Mutation rate λ (per hour and 10^8 cells)	Selection coefficient s (%)
358	3.16	9.5	....	...
347	3.80	7.9	1.7±0.14	12.7
159	3.60	8.3	1.4±0.06	4
147	3.60	8.3	1.6±0.08	2.5
118	3.40	8.8	1.8±0.12	3.5
112	3.13	9.6	....	...
99	3.20	9.4	2.5±0.19	4.4
90	3.20	9.4	2.6±0.14	3.5
89	3.20	9.4	2.5±0.07	6.1
89	2.32	12.9	....	...
74	1.30	23.1	3.8±0.17	7.0
67	1.30	23.1	4.2±0.28	13.2

TABLE 3

MUTATION RATES IN STRAIN B/R *hi-5* AND TWO *f* DERIVATIVES

GENERATION TIME τ (MIN.)	MUTATION RATE PER HOUR AND 10^8 CELLS		
	B/r *hi-5*	B/r *hi-5* f_1	B/r *hi-5* f_2
147	1.6±0.08	1.7±0.3	..
73–74	3.8±0.17	5.4±0.5	..
67	4.2±0.28	....	22

Such *f* strains appeared spontaneously in prolonged experiments, after population shifts which were generally indicated by a sharp discontinuity or drop in the accumulation of T5-resistant mutants. In an experiment in which B/r *hi-5* was grown at a generation time of 67 minutes, two successive population shifts occurred. During the second shift a new *f* strain (f_2) replaced the previous fast grower in the growth tube. The new strain mutated to T5 resistance at a rate as high as 2×10^{-7} per hour and per cell, or about 5 times as frequently as the original *hi-5* strain.

BACTERIAL GENETICS—II

Evelyn M. Witkin and Constance T. Thomas

In the past year our work with *Salmonella typhimurium* has been concerned primarily with three problems: (1) the timing of incorporation of genetic specificity in transduction; (2) the nature of the process of ultraviolet-induced mutation; and (3) the effects of ultraviolet light on the growth patterns of bacterial populations.

Transduction

We have continued our study of the timing of some critical events in transduction, with particular attention to the process of incorporation of the genetic specificity of the donor strain into the genotype of the recipient. In last year's report, we described the analysis of the composition of *Salmonella* clones in which transduction from histidine requirement to prototrophy had occurred. Our finding that such clones were invariably mixed, containing cells having the genotype of the wild-type donor as well as cells of the recipient type, supported the view that incorporation occurs most often in one daughter cell at the time of the first or second division after infection. We have analyzed the composition of nine additional clones in which transduction to prototrophy occurred after infection of *hi-23* with phage grown on the wild type; the total number of such clones analyzed to date is twenty. The percentages of prototrophs in these colonies were as follows: 83, 52, 51, 49, 40, 37, 36, 35, 32, 31, 29, 29, 24, 18, 14, 11, 9, 7, 0.01, and 0.01.

We have also made a study of the composition of six clones containing transduced cells arising by infection of another recipient strain, *try-3,* with phage grown on the wild type. The clones containing the transduced cells were detected by the replica-plating method, described in last year's report. They were found to contain the following percentages of prototrophs: 46, 25, 22, 11, 3, 1. These additional analyses provide further evidence that the specificity of the donor is usually transferred to a fraction of the daughter cells (most often, probably, to just one) during the course of the first few divisions after infection.

Our work in transduction has been done primarily with temperate phage and sensitive bacteria. Recently, we did some exploratory work using virulent phage to transduce lysogenic bacteria. The efficiency of transduction in this system is somewhat lower than in the temperate-sensitive system, and the results of different experiments are somewhat more variable. The most striking difference, however, was found in respreading experiments, in which the rate of increase in the size of clones composed of the transduced prototrophic type was compared with the rate of increase of clones composed of nontransduced cells. These experiments can be interpreted as reflecting something of the timing of incorporation of the donor's genetic specificity, especially when taken in conjunction with analyses of the final composition of colonies containing transduced cells. In the case of the temperate phage–sensitive bacteria system, the respreading experiments revealed a lag of one to two divisions for the transduced

type, consistent with the interpretation that incorporation of the donor's specificity occurs in an early division and in a part of the clone. In the case of the virulent phage–lysogenic bacteria system, respreading experiments with several different mutants as recipients suggested extreme delay in the time of incorporation of the donor's specificity.

Induced Mutations in Bacteria

In last year's annual report (Year Book No. 53, 1953–1954, pp. 241–246), we presented results of experiments in which the pattern of delayed appearance of ultraviolet-induced mutants was compared with that of the corresponding genetic types produced by transduction. It was found that four different nutritionally deficient strains of *Salmonella* gave rise to the maximum yield of induced prototrophs only under conditions permitting the irradiated cells to pass through 5 to 13 divisions, whereas prototrophs arising in the same strains after infection with transducing phage were fully detectable under conditions permitting only 1 to 4 residual divisions of the infected populations. This was interpreted as evidence that the primary factors responsible for delay in the appearance of induced mutants (induction delay) must arise from events directly associated with the mutation process, rather than from such secondary effects as phenotypic lag, nuclear segregation, or the nongenetic consequences of ultraviolet irradiation, all of which would be expected to contribute equally to induction delay and transduction delay. Our efforts during the past year, directed toward the further resolution of this problem, have led us to a re-evaluation of the nature of the so-called "delayed effect," and to a better understanding of the timing of the induced-mutation process.

A substantial improvement was made in the experimental procedure used to compare induction delay and transduction delay. In our previous work, transducing phage was grown initially on the wild type, so that the genotype of the prototrophs produced by infection with this phage was presumably identical with the wild type. It cannot be assumed that this is true of prototrophs induced by ultraviolet light, and, indeed, the induced prototrophs often show demonstrable differences from the wild type in such characteristics as growth rate and colony morphology. Thus, our earlier comparison of induction delay and transduction delay was subject to the criticism that the prototrophs arising by the two processes may not have been genetically identical. A modified procedure was developed, using a tryptophane-requiring strain (*try-3*). After exposure to ultraviolet light, *try-3* was plated on semienriched minimal medium and incubated to permit the development of colonies of induced prototrophs. A number of these colonies were picked; and, after an extensive series of tests indicating that they were characterized by a high degree of genetic homogeneity, one of the colonies was established as a stock, designated $try\text{-}3^{+-uv}$, and this stock was used as the donor strain in the transduction experiments. In this way, we could be reasonably certain that the prototrophs produced by ultraviolet induction and those arising by transduction were genetically identical.

The following procedure was used to compare the patterns of induction delay and transduction delay. A 24-hour aerated broth culture of strain *try-3* was washed twice by centrifugation, resuspended in an equal volume of buffer, and assayed for titer. An 8-ml aliquot of the suspension was then placed in an empty, sterile Petri dish, irradiated with 300 ergs/mm^2 of ultraviolet light, and assayed for survival (usually about 20 per cent). The irradiated suspension was then divided into two equal portions. To the first, transducing phage (grown on the previously isolated ultraviolet-induced prototroph) was added. To the second, nontransducing phage (grown on *try-3*, and therefore incapable of transducing this strain to prototrophy) was added. In both cases, the multiplicity

of infection was about 5. Aliquots of 0.1 ml of each suspension, containing about 4×10^7 infected survivors, were plated on minimal agar partially enriched with various amounts of nutrient broth, permitting the *try-3* cells to undergo a range of residual divisions from 0 to 8. The platings from the first portion, after two days of incubation, gave rise to prototrophic colonies originating by transduction or by ultraviolet induction, while only induced prototrophs appeared on the platings from the second portion. Since the frequency of induced prototrophs was only about 10 per cent of that of prototrophs resulting from transduction under the conditions used, it was possible to follow separately their patterns of appearance as a function of increasing levels of residual division.

The expression curves obtained in these experiments are shown in figure 5. The results confirm our earlier studies in showing that for a given strain, induction delay is more extensive than transduction delay: the maximal yield of induced prototrophs can be obtained only under conditions permitting 5–6 divisions, whereas those arising through transduction are fully detectable under conditions permitting only 1–2 divisions. We drew from these experiments the more rigorously established conclusion that the primary factors responsible for induction delay must arise directly from a specific differentiating state of the potential induced-mutant cell. Our next goal was to obtain information about the nature of this special condition.

Two possible properties of a potential induced-mutant cell have been postulated to account for induction delay. The first is a condition of more or less persistent genetic instability, resulting from the production of either intracellular mutagens or metastable molecular configurations in critical regions of the genetic material. On either basis, mutations would be expected to occur at an unusually high rate during the divisions following irradiation, and the pattern of delay would depend on the rate of decay of the unstable element. The second postulate is based on a possible association between the occurrence of induced mutation and exceptionally delayed onset of multiplication. An unusually long lag in growth could be associated with induced mutation either as a parallel but independent consequence of particularly heavy damage in a small fraction of the survivors, or as a manifestation of metabolic disturbance caused by the genetic changes occurring at random among the surviving cells. In either case, such an association could lead to an exaggerated

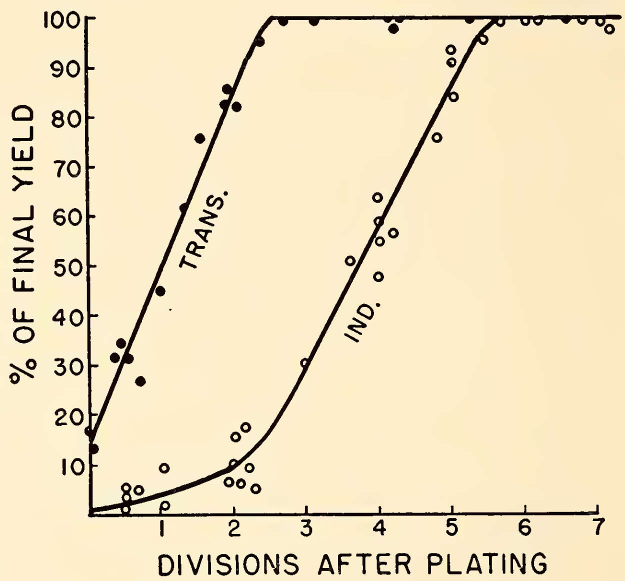

Fig. 5. Expression curves of prototrophs obtained from *try-3* by transduction and by induction with ultraviolet light.

estimate of the actual delay as measured by the expression curve.

The latter possibility was subjected to an experimental test, using the respreading technique of Newcombe (1949). If it is true that induced mutations appear primarily in clones that start to multiply after an unusually long lag period, it follows that the average number of cells per clone in the irradiated population at large should be demonstrably larger, during the early divisions, than the number of cells per induced-mutant clone. The average number of cells per clone was measured for the population as a whole by plate-washing after various intervals of time, and for the induced mutants by respreading, to sepa-

rate the individual members of each clone, at the same time intervals. It was found that the induced-mutant clones began to show a logarithmic increase in average cell number after only a slight delay as compared with the nonmutant population, the difference amounting to less than the time required for a single division. Even this small difference diminished further when the experiment was done in another way, to take into account the difference in growth rates of the mutant and nonmutant types on semienriched minimal agar. The induced prototroph, on this medium, grows somewhat more slowly than the tryptophane-requiring parent strain, and this difference contributed to the relatively slower increase in cell number per clone observed for the induced mutants in the respreading experiment. To eliminate the growth-rate difference from consideration, we compared the rate of increase of clone size of newly induced prototrophs with that of previously isolated induced prototrophs added to a population of ultraviolet-killed tryptophane requirers. In both cases, respreading was used to measure the increase in average number of cells per clone, and it was found that at any given time during early logarithmic growth, the clones of newly induced mutants consisted of about 80 per cent as many cells as the clones of mutants in the reconstructed population. There is no doubt, therefore, that induced mutants arise primarily in clones that are *not* particularly delayed in onset of multiplication. The apparent delay of 5–6 divisions in the appearance of induced mutants shown by the expression curves cannot be accounted for by an association between prolonged lag and the probability of mutation.

Thus, after successive eliminations, only the hypothesis of true delayed mutation seemed to remain to account for the expression curves of induced mutants. According to this idea, the irradiation sets up a condition of genetic instability that persists for 5–6 generations after treatment in the case of *try-3,* and causes a high rate of mutation to prototrophy during this period.

In spite of the fact that we considered the evidence eliminating the other hypotheses to be conclusive, a number of contradictions in the total picture made it difficult to accept the delayed-mutation hypothesis readily. Two of these seemed to be of major importance. First, there was the question of the genetic composition of the clones in which induced mutations appear. If induced mutations typically occur during a more or less persistent period of instability, lasting for several generations, the clones in which such mutations are detected should consist of a mixture of mutants and nonmutants, with the proportion of mutants lower in some clones as the period of instability is extended. Direct information concerning the composition of clones containing induced mutants is available for two different mutations, and indirect information for a third. Newcombe and Scott and Visconti analyzed the composition of a total of ten clones containing phage-resistant mutants of *Escherichia coli,* detected without the use of phage as a selective agent. Six of these clones proved to be purely phage resistant, whereas four were mixtures of sensitive and resistant cells. Since no special precautions were taken to eliminate the effects of segregation from multinuclear cells, the proportion of mixed clones is, if anything, overestimated. It seems likely, therefore, that induced phage resistance arises most often in pure clones, in spite of the twelve-generation delay suggested by the expression curve for this mutation. In the case of lactose-negative mutants induced by ultraviolet light in *E. coli,* the ratio of pure clones of the mutant type to mixed clones containing also the parental lactose-positive type is 11:1 when the effects of nuclear segregation are eliminated by special techniques (Witkin, 1951). In the case of prototrophs induced by irradiation of *try-3* in *Salmonella,* the respreading experiments described earlier provide indirect information which strongly suggests that the pa-

rental type is either absent from or present only in small numbers in a clone in which the induced mutation has occurred. The apparent prevalence of pure clones of induced mutants is difficult to reconcile with the hypothesis of persistent genetic instability; it is more consistent with the view that the genetic changes produced by ultraviolet light are manifested before the completion of the first postirradiation division.

Another set of facts that seems to contradict the hypothesis of delayed mutation has been derived from the study of the effects of postirradiation temperature on the frequency of induced phage-resistant mutants in *E. coli* (Witkin, 1953). It was found in these experiments that the yield of induced mutants was profoundly influenced by the temperature of incubation of the irradiated cells, and that the temperature-sensitive period was limited to the first division after treatment. Berrie (Year Book No. 52, 1952–1953, p. 218) also investigated the effects of postirradiation temperature on a wide variety of mutations in *E. coli,* and found that the yield of induced mutants was influenced by temperature in most cases only during the first third of the lag phase after ultraviolet irradiation. We have conducted an extensive series of experiments during the past year to test the effects of temperature on frequency of induced prototrophs obtained from irradiated *try-3,* and the results are in qualitative agreement with those obtained earlier with *E. coli.* Table 4 shows the induced-mutation frequency obtained when irradiated cells were incubated at 45°, 37°, 24°, and 15° C. There was no significant effect of postirradiation temperature on the survival level, nor any on the number of residual divisions, so that the number of survivors participating in multiplication at all four temperatures was about the same. There was a large effect of temperature on the yield of induced mutants, ranging from 0 per 4×10^7 cells at 45° C to about 300 per 4×10^7 cells at 24° C. More important than the mere fact of a temperature effect is our finding with regard to the temperature-sensitive period. We have found that, as in *E. coli,* the frequency of induced mutants is determined by the temperature of incubation during a fraction of the first postirradiation division, subsequent changes in incubation temperature having no further effect. This was found in a series of experiments in which irradiated *try-3* cells on semienriched minimal plates were incubated for increasing periods of time at one temperature, and then permitted to complete the period of residual growth (about 6 divisions) at a second temperature. In all cases, the final yield of mutants when the initial temperature was maintained for the period of the first division was the same as the yield when the initial temperature was maintained throughout the period of multiplication.

(An unusual feature of the temperature results in these experiments was the striking increase in frequency of induced mutants when the irradiated cells were incubated for short periods at a high temperature [37° or 45° C] and then allowed to complete residual division at a low temperature [24° or 15° C]. For example, after 45 minutes at 37°, followed by completion of residual division at 24°, the yield of induced mutants was found to be about 600 per 4×10^7 cells, about twice the number obtained at 24°, and five times as high as the normal 37° yield.)

These results provide another indication that the genetic changes produced by ultraviolet light are established relatively early, and that the hypothesis of persistent genetic instability is difficult to reconcile with the known facts.

As a result of these considerations, it seemed advisable to re-examine the basic assumptions involved in the methods of deriving expression curves. In the case of induced prototrophs, the method used was the technique of limited enrichment, described in detail by Demerec and Cahn (1953), and used extensively in many laboratories. The number of residual divisions of a standard inoculum of survivors

of ultraviolet treatment is regulated by plating on a series of minimal plates supplemented with increasing amounts of nutrient broth. For a particular strain, the population ceiling that a plate enriched with a given amount of broth can support is fixed, and the number of residual divisions of a standard inoculum can be predicted with accuracy. The expression curve describes the relation between the number of residual divisions and the number of induced mutants obtained from the standard inoculum. It has always been assumed, because in most strains increasing numbers of residual divisions are accompanied by increasing yields of induced mutants, that extensive residual division is required for the maximum expression of induced mutants. It seemed to us that this was not necessarily so, and that both variables might be more or less independent consequences of some other effect of different enrichment levels. To put this possibility to a direct test, we devised an experimental procedure that made it possible to determine whether or not the apparent relation between residual division and frequency of induced mutation is invariable.

Irradiated *try-3* cells were plated on minimal medium enriched with a small amount of nutrient broth (0.2 ml per 400 ml of minimal agar, designated as 0.2e). As would be expected on the basis of our previous experience in obtaining data for expression curves, the standard inoculum of 4×10^7 viable irradiated cells passed through an average of one division on these plates, and gave rise to about 5 per cent of the potential yield of induced prototrophs after two days of incubation at 37° C. When this incubation period was over, the agar disk bearing the irradiated *try-3* cells and the small number of induced prototrophic colonies was lifted from the plate with a spatula and deposited on the surface of another plate containing minimal medium enriched with 20 ml of nutrient broth per 400 ml of agar (20e). In such a case the nutrient broth present in the lower layer of more highly enriched agar diffuses rapidly into the upper layer, and the enrichment of the two layers is equilibrated at about the 10e level within one hour. Our experience showed that the standard inoculum of irradiated *try-3* at this level of enrichment passes through an average of 6 divisions, and gives rise to the maximum yield of induced prototrophs. We expected that, after equilibration of the enrichment level, the *try-3* cells on the surface of the upper layer would resume residual division, and

TABLE 4

EFFECT OF POSTIRRADIATION TEMPERATURE ON THE FREQUENCY OF ULTRAVIOLET-INDUCED PROTOTROPHS OBTAINED FROM *try-3*

(UV dose, 300 ergs/mm^2)

Temperature during postirradiation division on 10e plates (° C)	% survival *		Final no. residual divisions *		No. induced prototrophs per 4×10^7 survivors plated †	
	Expt. 1	Expt. 2	Expt. 1	Expt. 2	Expt. 1	Expt. 2
45	16.2	22.5	5.8	5.1	0	0
37	18.7	21.5	5.4	5.9	139	122
24	21.1	24	5.3	5.3	262	333
15	19.4	20.6	6.1	5.8	26	41

* Each figure based on average of four plate counts.
† Each figure based on average of three plate counts.

would pass through about 5 additional divisions. This did indeed occur, and the final number of residual divisions was the same as that obtained when the irradiated cells were plated directly on the high enrichment. We found, however, that the resumption of residual division was not accompanied by any further development of induced prototrophs, and that the only induced mutants on the plates were the few that had appeared after the initial incubation on the low enrichment. These results provided the first direct indication that the number of residual divisions is not critically related to the yield of induced mutations, and that the mutation frequency is determined by the level of enrichment during the first postirradiation division.

We then began a series of experiments similar to the one described above, in which the time before "transplantation" of the irradiated cells from a low enrichment to a relatively high one was gradually decreased. We found that incubating the cells on 0.2e plates for ½ hour before transplanting to 20e plates was sufficient to limit the appearance of mutants to 5 per cent or less of the maximum yield, in spite of the fact that 6 residual divisions occurred. Taking into account the time required for equilibration of the enrichment level, this means that irradiated cells incubated on a low-enrichment medium for about 1 to 1½ hours (one-third to one-half of the lag phase) are unable to give rise to a high yield of induced mutants if the level of enrichment is increased after that time. These results are strikingly similar to those obtained in the temperature studies, in showing that the yield of induced mutations is determined by conditions prevailing in the first part of the first division after irradiation.

Figure 6 summarizes the results of the experiments in which irradiated cells were incubated on low enrichments for ½ hour and then transplanted to high enrichments. In all cases, the final level of residual growth was at least 6 divisions, but it is evident that the mutation frequency depends on the amount of enrichment present during the initial incubation. The "expression curve" obtained from these transplantation experiments is identical with that obtained without transplanting to high enrichments. We have thus shown that the amount of nutrient broth present in the minimal agar during the first one-third to one-half of the lag phase determines the yield of mutations, and that the increasing numbers of residual divisions are merely parallel and nonessential consequences of the increasing enrichment levels.

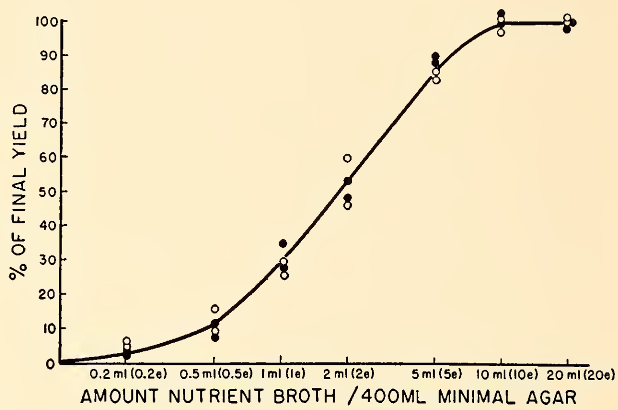

Fig. 6. Expression of ultraviolet-induced prototrophs obtained from *try-3* on minimal medium enriched with different amounts of nutrient broth. Open circles, irradiated cells plated on enrichment indicated, and incubated 2 days. Closed circles, irradiated cells plated on enrichment indicated, incubated ½ hour, then "transplanted" to 20e plates and incubated 2 days.

An important check on the validity of this conclusion was a transplantation experiment in reverse, that is, incubation of the irradiated cells on a high enrichment for the critical period of the first division, and then removal to a low enrichment that would permit little or no further residual growth. If our conclusion was correct, we should obtain the maximum yield of induced mutations under these conditions, in spite of the fact that the final number of residual divisions would not exceed one or two. Experiments of this type, obviously, could not be performed by the method of transplanting layers of agar,

since the level after equilibration would be too close to the initial high level to permit sufficient limitation of residual growth. The procedure used, therefore, was to incubate irradiated cells on high enrichments (10e plates) for one hour, then wash them from the surface and replate on minimal plates containing no added enrichment. The final level of residual growth after incubation was about 1.5 divisions, and the yield of induced mutations, as predicted, was 100 per cent.

Thus, induced-mutation frequency can be dissociated from residual division in two ways: high yields of mutants can be obtained with only 1 to 2 residual divisions; and low yields of mutants can be obtained with 6 or more residual divisions. To summarize our conclusions from these experiments, it can be stated that the yield of induced mutants obtained from a given inoculum of irradiated cells is a function of the amount of nutrient broth present in the agar during the first part of the postirradiation lag period. It should be emphasized that there is no effect of different enrichment levels on the survival of the irradiated *try-3* cells, so that the differences in mutation frequency cannot be regarded as "recovery" effects in the usual sense.

Having established that the amount of nutrient broth present during the first postirradiation division determines the yield of induced mutants, we turned our attention to the question of the way in which this control is exercised. Specifically, we sought to determine how increase in the amount of nutrient broth was important in determining increased induced-mutation yield. Our first approach was to examine the growth rates of irradiated cells on increasingly enriched minimal agar; and we found that as the amount of enrichment increased, the length of the lag phase and the generation time decreased, until the 10e level was reached. With this amount of enrichment, the growth curve became identical with that obtained on complete nutrient agar; and since this was also the enrichment level required to give the full potential yield of mutants, it seemed that the timing of the division process was an important factor. We developed a working hypothesis based on this assumption, but in the course of subsequent experiments a new set of facts emerged that rendered our hypothesis untenable, at least in its simplest form.

The new facts arose from experiments in which tryptophane, the specific growth factor required by *try-3,* was used as the source of enrichment rather than nutrient broth, which had been used throughout as a matter of common laboratory practice. We found that essentially no induced mutants were obtained on minimal plates enriched with an amount of tryptophane comparable in its growth-supporting properties to that present in 10e plates. It was immediately apparent, since the growth rates of the irradiated cells on comparable levels of tryptophane and nutrient broth are not grossly different, that the timing of the division process is not necessarily a major factor, but that some particular component of nutrient broth other than the growth-controlling tryptophane must be present during early growth if induced mutants are to be obtained. By supplementing tryptophane-enriched plates with a pool of amino acids other than tryptophane, a pool of vitamins, and a pool of purines and pyrimidines, we found that tryptophane-enriched plates to which a pool of other amino acids had been added would support the appearance of induced mutants as effectively as plates enriched with nutrient broth. We are now able to state that irradiated cells will give rise to the full yield of induced mutants if they are grown for one division in the presence of amino acids. We have begun to investigate the relative effectiveness of single amino acids and combinations of various types. Our evidence thus far permits us to say only that no single amino acid is fully effective, that different combinations show a range of varying effectiveness, and that a few combinations appear to give

higher yields of mutants than a pool of all amino acids.

Another interesting aspect of the amino acid effect is related to the previous history of the culture used. We have routinely grown our *try-3* cells in nutrient broth, and used washed suspensions of these cells in buffer for irradiation. After discovering the amino acid effect, we did some experiments using *try-3* cells grown initially in minimal medium supplemented with tryptophane. We found that such cultures, "adapted" by their conditions of growth to making their own amino acids other than tryptophane, were less dependent on amino acids in the external medium for the production of induced mutants than were cells grown initially in broth. Cells grown in tryptophane-supplemented minimal medium were able to produce about half the potential yield of induced mutants on plates containing no amino acids other than tryptophane, whereas broth-grown cells yielded no induced mutants whatever unless amino acids were added to the postirradiation growth medium.

Although these experiments have shown clearly that extensive residual division is not required to obtain ultraviolet-induced prototrophs from *try-3,* several lines of evidence suggest that induced mutations cannot be obtained unless the process of cell duplication is initiated and permitted to proceed at least to the point of near completion of the first postirradiation division. First of all, irradiated cells fail to yield induced prototrophs when incubated on minimal medium containing no tryptophane but supplemented with all the other amino acids. Second, irradiated cells fail to produce the maximum yield of induced prototrophs if incubated for short periods of time on high enrichments and then replated on unsupplemented minimal medium in such a way as to limit the final amount of residual division to an average of less than one. Finally, irradiated cells maintained in buffer at 37° for as long as 6 hours remain "frozen" in their capacity to produce induced prototrophs when plated out on growth-supporting media, a fact which suggests that the chain of events leading to the determination of the genetic change is associated with the metabolism of the division process. Another interesting observation is based on an experiment done jointly with Kanazir, of this Department, who followed the synthesis of DNA in irradiated *try-3.* He found that DNA increased logarithmically from the moment of irradiation; and examination of the curve he obtained revealed that the time required for doubling of the initial level of DNA corresponded to the temperature-sensitive period and to the period of sensitivity to the amino acid concentration—approximately one-third of the lag phase. It appears possible that the critical period corresponds to the period of chromosome duplication, and that the frequency of induced mutations is irreversibly determined by conditions prevailing during this phase of cell division.

It is important, of course, before discussing the significance of these findings, to have some idea of their generality. We know already, from work cited earlier, that the main features of the temperature effect apply in the case of a wide array of different mutations in both *E. coli* and *Salmonella.* We have examined another *Salmonella* auxotroph, one requiring adenine for growth, and have found that the appearance of induced prototrophs in this strain is dependent on the presence of amino acids during the early period of the first postirradiation division, in much the same way as is true of induced prototrophs in *try-3.* An important part of our subsequent work will be to extend the range of mutations investigated, as well as to study the action of mutagens other than ultraviolet light.

At this stage of our study, we are unable to present any single working hypothesis concerning the mechanism of ultraviolet-induced mutation that is consistent with all the known facts. We can say only that the genetic changes produced by ultravio-

let light are indirect, and that their realization appears to depend on metabolic conditions prevailing during the early stages of the first cell division after irradiation. Beyond this point, speculation takes over.

One convenient framework of thinking involves the postulation of a mutagenic substance produced in the irradiated cell. The influence of temperature and medium during the early stages of growth could be accounted for as affecting (*a*) the rate of production of the mutagen, (*b*) the rate of decay of the mutagen, and (*c*) the rate of cell division. By assigning different temperature coefficients to each of these three processes, and by assuming that mutation requires the presence of a high level of mutagen during a critical stage of cell duplication, it is possible to account for the main features of the temperature studies. We are attempting a more direct test of this possibility by determining whether or not irradiated cells have mutagenic potency for nonirradiated cells.

It is equally possible to evaluate our findings on the assumption that irradiated cells have the capacity to yield induced mutants as a result of metastable configurations in critical regions of the genic material itself. The decay of this unstable state in relation to the timing of cell division could account for many aspects of the results.

A third viewpoint, and one that is perhaps most difficult to approach experimentally, is the possibility that the appearance or nonappearance of induced mutants reflects the survival or nonsurvival of genetically damaged cells. It is quite possible that the fate of such damaged cells is fluid, and that their recovery as nonmutants or as mutants, or their failure to survive, may be the dimension in which the postirradiation effects we have described are operating.

Effect of Ultraviolet Light on the Lag Phase of Individual Irradiated Cells

It is well known that irradiation with ultraviolet light usually causes a prolongation of the lag phase of the surviving bacterial cells. Since the lag phase is ordinarily measured as the average time required for a large population of bacteria to enter the phase of logarithmic increase, it has not been possible to determine directly whether or not the extension of the lag phase caused by ultraviolet is accompanied by increased variability in the time of onset of division of individual cells. The possibility has been suggested that a small fraction of the surviving organisms begin to divide very early, imposing their growth pattern on the total population when their descendants become sufficiently numerous. If this were true, measurements of the growth of irradiated populations based on the average increase could be grossly misleading. Since a knowledge of the growth behavior of irradiated cells is an essential part of induced-mutation studies, it seemed important to obtain direct information about the range of variability in time of onset of logarithmic division in ultraviolet-treated populations. For this purpose we have developed a modification of the Newcombe respreading technique, based on a suggestion made by Dr. Bruce Wallace, which makes it possible to follow the early growth rates of individual clones.

Suspensions of *try-3* (irradiated or not) containing about fifteen viable cells are spread evenly on the surface of minimal agar plates enriched with enough nutrient broth to permit the development of visible colonies. (Enriched minimal medium, rather than complete medium, is used because limitation of the size of the colonies on the plates increases the accuracy of the counts.) A pattern of 44 1-cm squares is drawn on the bottom of each plate, and a mark is placed in the center of alternate squares, checkerboard fashion, so that no two adjacent squares are marked. After various periods of incubation, the plates are removed from the incubator in sets of four, and the unmarked squares on each plate are respread to separate the cells constituting microcolonies. The respreading

is done with a glass spreader bent in such a way as to have three 1-cm spreading surfaces in the same plane, separated by indentations of the same length. Thus three unmarked squares are respread simultaneously by applying the spreading surfaces to the lower edges of the squares and moving them several times from the lower to the upper edges and back again. The spreader is first sterilized in alcohol, flamed, and dipped in sterile saline to provide the moisture necessary for efficient separation of the cells composing a microcolony. The marked squares are undisturbed, and serve to reveal the original distribution of potential clones. When the total number of clones per plate is small (15 or fewer), the probability of respreading more than one clone per square is slight. Growth curves obtained by the "checkerboard" method agree reasonably well with those obtained by plate-washing, up to the level of 3–4 generations. The efficiency of the method is affected by the precision with which the respreading movements are confined within the limits of the squares, and by the thoroughness of the respreading in separating members of a clone. Figure 7 shows three checkerboard plates, initially seeded with aliquots from the same suspension, and respread after different periods of incubation.

The results were analyzed by counting the number of control (undisturbed) squares containing any colonies, and calculating the percentage of these that contained only one colony ($P1_0$). This gave a measure of the proportion of squares initially seeded with a single cell, and in most experiments the value was about 85 to 90 per cent. For each respreading time, the proportion of spread squares containing only one colony ($P1_t$) was determined, and it was thus a simple matter to calculate for each time point the proportion of bacteria that had not yet completed one cell division: $(P1_0 - P1_t)P1_0$ = percentage of cells not yet divided.

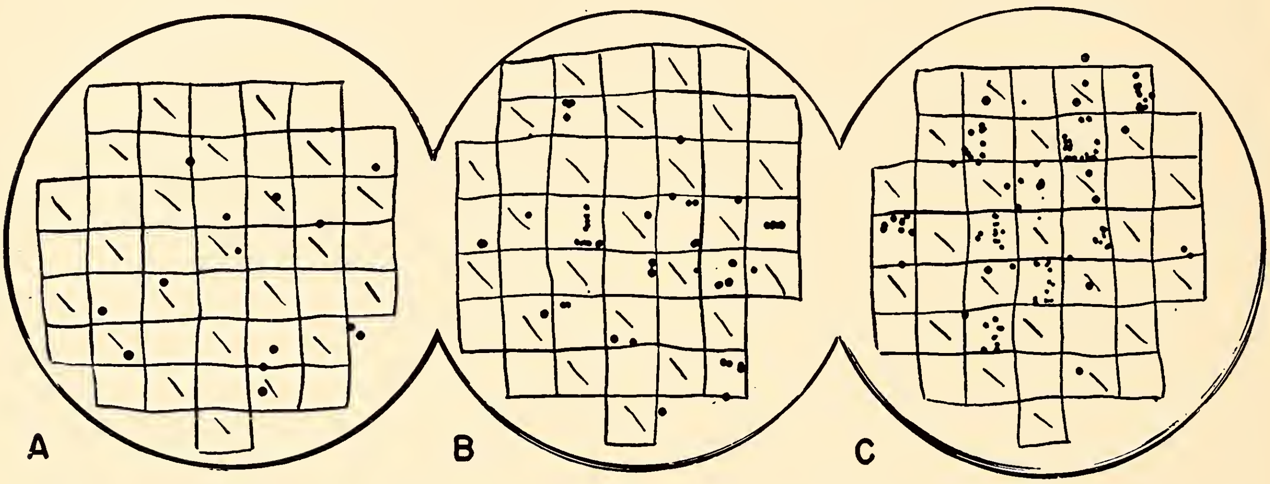

FIG. 7. "Checkerboard" plates. *A,* unmarked squares respread immediately after plating. *B,* unmarked squares respread after incubation period of 1½ hours at 37° C. *C,* unmarked squares respread after incubation period of 2½ hours.

Table 5 shows the percentages of undivided cells in nonirradiated and irradiated populations when the average number of divisions is about 1, 2, 3, and 4. It will be seen that the variability in onset of division is similar in the two populations, except that about 10 to 15 per cent of the cells in the irradiated cultures seem to be exceptionally delayed in undergoing first division. There is no small fraction of cells that begins to divide exceptionally early. Induced mutants do not arise preferentially from the exceptionally slow fraction of the population, for the respreading experiments described earlier in the section on induced mutations reveal that

clones of induced mutant cells increase almost as rapidly as nonmutant clones.

The checkerboard method can be adapted for use in connection with a variety of problems, wherever it is desirable to measure the growth rate of individual clones as opposed to average growth rates of large populations. It could be of particular value in estimating the efficiency of procedures designed to bring about synchronization of bacterial growth.

TABLE 5

EFFECT OF ULTRAVIOLET LIGHT ON DISTRIBUTION OF LAG-PHASE TIMES IN INDIVIDUAL SALMONELLA CLONES

(Strain *try-3* grown 18–24 hours in nutrient broth with aeration, washed and resuspended in buffer, plated on semienriched minimal medium [10e]. UV dose, 300 ergs/mm^2; survival, ca. 20%.)

Expt. no.	Nonirradiated population		Irradiated population	
	Av. no. divisions	% cells not yet divided	Av. no. divisions	% cells not yet divided
1	1.1	50.1	0.9	51.0
	2.3	23.2	2.0	25.5
	2.9	10.6	3.2	17.3
	4.1	2.1	4.2	13.2
2	0.9	48.3	1.1	47.3
	2.1	26.8	2.2	24.9
	3.1	9.4	2.9	14.3
	4.0	1.6	3.9	12.1

CONTROLLED MUTATION IN MAIZE

BARBARA McCLINTOCK

Experimentation conducted during the past year was aimed at expanding our knowledge of the kinds of elements carried in the maize chromosomes that control gene action and give rise to changes in this action, that is, to mutations. Different controlling elements have been recognized, each characterized by its own specific mode of control of gene action and mutation; and this mode of control is quite independent of the primary type of action of the genic materials themselves, which these elements may serve to modify. Their presence in the chromosome complement is made evident because they undergo transposition from one location to another and do not lose their specificity of action in the process. Were it not for such behavior, these elements would remain undetected. Insertion of a controlling element at a locus of known gene action results in immediate or subsequent change in this action, or both. Each element expresses its own mode of control of change in gene action, and this allows the presence of the element at the locus to be recognized. The same element may be inserted at a number of different locations and thus come to control the action of genic materials at each of these locations. Conversely, the action of the same genic material may be influenced by different controlling elements, as a result of independent insertions of such elements at one particular locus.

Evidence of the control of gene action and mutation at a number of different known loci in maize by the *Ds-Ac* two-element controlling system has been reported in past years. Knowledge gained

from concentrated attention to the mode of operation of this particular system has provided the basic information that now serves as a guide in planning experimentation and in interpreting the modes of operation of other controlling elements or of systems of interrelated elements. With this framework of knowledge, advances in these studies may be made much more rapidly and effectively. In the past year, attention has been given to a system that differs considerably from the *Ds-Ac* system in its manner of control of gene action and mutation. A tentative hypothesis to account for the operation of this system was outlined in Year Book No. 53. Extensive tests have now been conducted, and the evidence obtained from them fully supports the hypothesis previously formulated. Much additional knowledge of the mode of operation of the system has also been obtained. A summary of this may now be given.

The a_1^{m-1}-*Spm* System of Control of Gene Action and Mutation

The A_1 locus in chromosome 3 of maize is a particularly favorable one for examining the operation of controlling systems. The genic materials at this locus are concerned with the development of anthocyanin pigmentation both in the plant tissues and in the aleurone layer of the kernel. When a change in intensity, quality, or pattern of distribution of that pigment appears in an individual plant or kernel, the altered phenotype is readily noticed. Therefore it is possible to detect insertions of controlling elements at the locus shortly after they occur. Different systems controlling gene action and mutation at this one locus have been recognized, and their modes of operation examined. Each was detected, initially, because of a distinct deviation from the standard A_1 type of expression of anthocyanin pigmentation, appearing either in an individual kernel on an ear or in an individual plant of a culture. Four of these systems have been analyzed in some detail and their modes of operation defined: the a_1-*Dt* (Dotted) system, the *Ds-Ac* system, the a_1^{m-1}-*Spm* system, and still another system operating at this locus to control the type and distribution of anthocyanin pigmentation in both kernel and plant. The system with which we shall be concerned in this section is the a_1^{m-1}-*Spm* system.

Knowledge of the behavior of controlling systems makes it evident that this one is composed of two interrelated but independently located elements. One of them, becoming inserted at the locus of A_1, caused a modification of the action of the genic materials located there. The modified locus has been designated a_1^{m-1} to distinguish it from other modifications that have arisen independently at this same locus. Subsequent changes have occurred at the locus, each effecting a change in gene action. These are regarded as arising from alterations of the controlling element. With a few possible exceptions, the genic materials themselves do not appear to be altered by such modifications. Their mode of action, however, may be decidedly altered as a result of any one change in the associated element. Thus the observed changes in gene action are referable, on the whole, to changes in the controlling element and not to irreversible changes in the gene substances. Moreover, such changes in gene action, stemming from alterations in the controlling element at the A_1 locus, can occur only when a second, independently located element is also present in the nucleus. The second element of this system is called Suppressor-mutator (symbolized as *Spm*), for the following reasons. In plants that either are homozygous for a_1^{m-1} or are a_1^{m-1}/a_1 in constitution, and that also have *Spm* in their nuclei, no anthocyanin pigment develops in the aleurone layer of the kernel or in the plant tissues until, in a somatic or a germinal cell, a modification of the controlling element located at A_1 allows pigment to be formed in those cells where it normally develops when the standard organization at the A_1 locus is present. These modifications effect

stable mutations, in that the altered type of gene action so produced continues to be expressed in subsequent cell and plant generations, both in the presence and in the absence of *Spm*. In plants of the above-named constitutions that do not have *Spm* in their nuclei, on the other hand, restricted gene action occurs, and this results in the appearance of uniformly distributed pigment both in the aleurone layer of the kernel and in the plant tissues. This expression of the genic substance at A_1 is constant and stable through successive plant generations as long as the *Spm* element is absent from the nuclei, for no mutations occur. Return of *Spm* to the nuclei, however, by appropriate crosses, again initiates the Suppressor-mutator effect on the element located at A_1. Gene action is again suppressed until, in a somatic or germinal cell, some change in this element allows the genic materials to function in some particular manner.

Unlike its counterparts, *Dt* in the a_1-*Dt* two-element system and *Ac* in the *Ds-Ac* two-element system, *Spm* does not show pronounced dosage effects that are reflected in altered frequencies or times of occurrence of mutation at the modified A_1 locus. Like other controlling elements, however, *Spm* undergoes transposition and consequently occupies no set position in the chromosome complement. An individual plant may have several *Spm* elements, each occupying a different site in the chromosome complement. Because it shows no dosage effects, the number of *Spm* elements present in the nuclei of a plant, as well as their locations within the chromosomes, must be determined by progeny tests.

In addition to the modifications affecting stable gene action, the element at A_1 also undergoes another type of change, but far less frequently. These changes, called "changes in state," are expressed by striking differences in the types of mutation that occur subsequently in the presence of *Spm*, and also in their times and frequencies of occurrence during development of each tissue. They also affect the degree of gene action that occurs in the absence of *Spm*. This varies among the states, and in this respect they form a graded series, from those that produce low levels of pigment intensity to those that give high levels. A few of the latter produce pigment intensities approximating that given by the genic materials at the standard A_1 locus. Nevertheless, with these latter states as with all states of a_1^{m-1} examined, pigment formation is completely suppressed in the presence of *Spm* and will appear only after the element located at A_1 undergoes some mutation-inducing event, or after *Spm* is removed from the nucleus. With respect to state it has also been found that the type of gene action that appears in the absence of *Spm* is not correlated with the types and patterns of mutation that appear in its presence. The states of a_1^{m-1} will be discussed more fully later.

Inheritance patterns of Spm. In Year Book No. 53, evidence was reported of linkage of *Spm* with *Y* (yellow endosperm), located in chromosome 6, in some plants of a particular culture (see table 17 on p. 257 of that Year Book). In these plants, only one *Spm* element was present. Their constitutions were a_1^{m-1} Sh_2/a_1 sh_2; *Y Spm/y* +. (The a_1 allele in these plants belongs to the a_1-*Dt* system of control of gene action. It does not respond to *Spm* and therefore behaves as a stable recessive in plants that have *Spm*. Shrunken endosperm, sh_2, is very closely linked to a_1 and shows less than one-quarter per cent crossing over with it.) When these plants were crossed by plants homozygous for a_1, sh_2, and *y* and having no *Spm*, the types of kernels on the resulting ears indicated that approximately 35 per cent crossing over had occurred between *Y* and *Spm* in the heterozygous parent plants. In the Sh_2 class there was a total of 1470 kernels. Of these, 723 were uniformly pigmented, showing a pale color in the aleurone layer (no *Spm* present); 269 of them were *Y* and 454 were *y*. In 740 of the Sh_2 kernels, spots of deep pigmentation appeared in a

colorless background (*Spm* present); 451 of these were *Y* and 289 were *y*. In addition, there were 7 completely colorless kernels; 4 were *Y* and 3 were *y*. Among the 1489 kernels in the sh_2 class, only 7 carried a_1^{m-1}; 3 of these were pale-colored (no *Spm*), and 4 had spots of deep color in a colorless background (*Spm* present). All other kernels in the sh_2 class had completely colorless aleurone; a 1:1 segregation for *Y* and *y* appeared among them. Plants were grown from selected kernels of all classes on these ears, and each was subjected to a particular set of tests. It was obvious that three major types of test were required: (1) verification of linkage of *Spm* with *Y* in plants derived from the variegated kernels in the Sh_2 *Y* class, (2) verification of the presence of a_1^{m-1} but the absence of *Spm* in plants derived from the uniformly pale-colored kernels, and (3) determination of whether or not *Spm* would be present in approximately 65 per cent of the plants derived from the a_1 sh_2 *Y* class of kernels and in approximately 35 per cent of the plants derived from the a_1 sh_2 *y* class of kernels.

Tests other than these three were also required. It was believed that somatic losses of *Spm* from some nuclei were occurring in some cases; this assumption was based on the presence in some plants carrying a_1^{m-1} and *Spm* of distinct sectors showing the phenotype that appears in the absence of *Spm*. Tests of the assumption could be readily carried out when such a sector extended into the tassel. Pollen collected from the sectorial and nonsectorial parts of the same tassel could be used in particularly designed test crosses (see below), which allowed detection of the presence or absence within the functional pollen grains of the *Spm* element and also of an a_1^{m-1} locus capable of responding to *Spm* in the expected manner. Such tests were made, and they fully confirmed the assumption that somatic losses of *Spm* from some nuclei occur during development.

In plants having one *Spm* element, transposition of *Spm* in some germinal cells can result not only in loss of *Spm* from some nuclei, as described above, but also in changes in its location, or increases in its number, in others. Since the rate of transposition of *Spm* appears to be relatively low, in view of the rather sharp linkage relations described, detection of cases of transposition required tests of relatively large numbers of individuals among the progeny of plants having one *Spm* element whose location was known. Such tests were conducted, and evidence of changes in location and increase in numbers of *Spm* elements was found.

Test (1) was extensive. It was accomplished by crossing each plant with one that either was homozygous for a_1^{m-1}, Sh_2, and *y* and had no *Spm* or was homozygous for a_1, sh_2, and *y* and had no *Spm*. For many plants both test crosses were made, and the results obtained in each test were the same except in a few instances where loss or change in position of *Spm* occurred early in an individual cell of the plant. Most of these were evident because of the fact that one of the ears produced by the plant was obviously sectorial with regard to *Spm* constitution. A plant homozygous of a_1^{m-1} but having no *Spm* is particularly useful for determining the presence or absence of *Spm* in another plant that is either a_1^{m-1}/a_1^{m-1}, a_1^{m-1}/a_1, or a_1/a_1 in constitution, and also for determining the numbers of *Spm* elements that may be present in such a plant. An intercross is made between the two plants. If *Spm* is present in the plant being tested, all the kernels that received it from gametes of this plant will show colored spots in a colorless background, and all those that did not receive it will be uniformly pale in color. With few exceptions, the ratio of variegated to pale kernels will indicate the numbers of *Spm* elements that were present in the zygote of this plant. The exceptions arise from early-occurring losses and transpositions of *Spm,* but the frequency of these is relatively low. If the tester

plant, which is homozygous for a_1^{m-1} and has no *Spm,* is also homozygous for some known recessive markers such as *wx, pr,* and *y,* and if the plant being tested is heterozygous for such markers, evidence of linkage of *Spm* to one or another of these markers, or evidence of absence of such linkage, is readily obtained.

Test (1), outlined above, verified the linkage of *Spm* with *Y* that had been observed in the parent plants, and the ratios of kernel types were the same as those shown by the parent plants. As expected, however, a few cases were encountered of change in location or increase in number of *Spm* elements, which had occurred in a germinal cell of the heterozygous parent plant. As an illustration of these tests, data obtained from fifty-six plants may be summarized. In forty-seven of them, linkage of *Spm* to *Y* was clearly expressed and to the same degree in each plant. Among the 7705 kernels in the pale class (no *Spm*), 2534 were *Y* and 5171 were *y*. Among the 7434 kernels in the variegated class (*Spm* present), 4862 were *Y* and 2572 were *y*. These data indicate that *Spm* is located approximately 35 crossover units from *Y*. In nine plants, the ratios of kernel types did not conform with this. In four of them, one *Spm* element was present but its linkage to *Y* was not expressed with certainty on any of the ears produced. Among a total of 1142 kernels on these ears, 533 had pale aleurone color (no *Spm*); 258 of them were *Y* and 275 were *y*. Among the 609 variegated kernels (*Spm*), 321 were *Y* and 288 were *y*. In two plants, two independently located *Spm* elements certainly were present. On each ear produced by these plants, a ratio of 1 kernel with no *Spm* to 3 kernels with *Spm* was observed. A total of 500 kernels was produced. In the class with pale-colored aleurone (no *Spm*), there were 117 kernels; 46 of them were *Y* and 71 were *y*. Among the 383 kernels in the variegated class (*Spm* present), 206 were *Y* and 177 were *y*. The data suggest that in both these plants one *Spm* element was carried in the *Y* chromosome and the other was located elsewhere. In the three remaining plants, the ratio of kernel types on the ears deviated in another way from that which might have been expected. Although the number of kernels on these ears was low, the deviation from a ratio of 1 *Spm* to 1 no-*Spm* was obvious: 27 to 70, 43 to 111, and 36 to 66. On none of these ears was there any evidence of linkage of *Spm* with *Y;* in the *Y* class there were 117 pale-colored kernels to 50 variegated kernels, and in the *y* class there were 129 pale-colored kernels to 58 variegated kernels. Frequent but late-occurring losses or transpositions of *Spm* may have been responsible for the observed deviation from the expected 1:1 ratio, although other causes may be considered. Progeny tests are required before any definite conclusions can be drawn regarding cause.

Test (3) is considered an important one because in the two classes involved, the presence or absence of *Spm* could not be determined by observation of type and distribution of anthocyanin pigmentation. All kernels were homozygous for a_1, and since this recessive allele of A_1 does not respond to *Spm,* anthocyanin pigment was absent in all kernels of these two classes. Tests for the presence or absence of *Spm* and for its location, if present, were conducted with fifty-six plants derived from the *Y* class of colorless, sh_2 kernels and with sixty plants derived from the *y* class of such kernels. Each plant was crossed by a plant homozygous for a_1^{m-1}, Sh_2, and *y* and having no *Spm*—the *Spm* tester stock described above. If no *Spm* was present in a plant being tested, all kernels on an ear resulting from this cross would be uniformly pale-colored. If one *Spm* element was present, half the kernels on an ear would be pale-colored (no *Spm*) and the other half would be variegated, with colored spots on a colorless background (*Spm* present). If more than one *Spm* was present, the ratio of variegated to pale kernels would be higher. With this mode of testing for *Spm,* it was possible to learn

that no *Spm* was present in twenty-four of the fifty-six plants derived from the *Y* class of kernels, and that in the remaining thirty-two plants one *Spm* element was present. Its linkage with *Y* was clearly expressed in thirty of these thirty-two plants. Among a total of 7792 kernels on the ears produced by the thirty plants, 3985 were uniformly pale-colored (no *Spm*); 1366 of them were *Y* and 2619 were *y*. The remaining 3807 kernels had a colorless background in which spots of deep color appeared (*Spm* present); 2472 of them were *Y* and 1335 were *y*. On the basis of these data *Spm* may be placed in chromosome 6, approximately 35 crossover units from *Y*. It will be noted that this is the same distance from *Y* indicated by the data from test (1), given above. The ratios of kernel types on ears produced by two of the thirty-two plants having one *Spm* element did not give clear evidence of linkage of *Spm* with *Y*. On one ear there were 70 pale-colored kernels and 88 variegated kernels. In the pale class, 30 were *Y* and 40 were *y;* in the variegated class, 47 were *Y* and 41 were *y*. On the ear of the other plant there were 123 pale kernels, 66 of which were *Y* and 57 *y,* and 154 variegated kernels, 79 of which were *Y* and 75 *y*.

Among the sixty tested plants derived from the a_1 sh_2 *y* class of kernels, seventeen had a single *Spm* element and forty-three had no *Spm*. On the ears produced by the seventeen plants having *Spm,* after the test cross described above, there was a total of 6746 kernels; 3465 of these were pale-colored (no *Spm*), and 3281 showed spots of deep color on a colorless background (*Spm* present).

These progeny tests again indicated that *Spm* was located in the *Y*-carrying chromosome 6 of the heterozygous parent plants, and again placed it approximately 35 crossover units from *Y*. In linkage studies with transposable elements, an error is always introduced into the calculations of crossover distances, and the degree of this is related to the frequency of occurrence of transposition of the element, before gamete formation, to new locations in the chromosome complement. As may be noted from the several tests outlined above, this frequency in the case of *Spm* is not great enough to have a serious effect on determinations of linkage relationships.

Test (2), mentioned earlier, was readily conducted, in several different ways. The plants being tested were assumed to be a_1^{m-1} Sh_2/a_1 sh_2 in constitution, and to have no *Spm*. The absence of *Spm* was confirmed in all cases by means of the test cross outlined above. The presence of a_1^{m-1}, carried in the Sh_2 chromosome and capable of responding to *Spm,* was readily determined by crossing these plants to plants homozygous for a_1 and sh_2, some carrying an *Spm* element and others lacking this element. On the ears produced by the latter cross, nearly all the Sh_2 kernels were pale-colored and, as expected, nearly all the sh_2 kernels were colorless; no variegated kernels appeared. On the ears produced by the former cross, however, the two expected classes of kernels appeared in the Sh_2 class: those showing spots of deep color on a colorless background (in which both a_1^{m-1} and *Spm* were present), and those showing a uniformly pale color (in which a_1^{m-1} was present but *Spm* was absent). Also, as expected, nearly all the sh_2 kernels were colorless. The location of *Spm* in the a_1 sh_2 parent was known in some cases, and the expected linkage with factors carried in the chromosome that also had *Spm* was made evident on the ears that resulted from their use in these crosses.

The tests outlined above have been described here in some detail in order to indicate the necessary initial analytical methods in an investigation of the basic mode of operation of this two-element system. With the general mode of operation defined, it was possible to conduct a number of further tests. Some of these were designed to determine the number of *Spm* elements present in individual plants of a particular progeny, when the presence of

two or more was suspected in the parent plant. Others were aimed at determining various locations in the chromosome complement that may be occupied by *Spm*. At present, two positions in chromosome 6, two in chromosome 5, and two in chromosome 9 have been identified. *Spm* also occupies other sites in the chromosome complement that have not yet been located. In another series of tests, individuals having two *Spm* elements, located at allelic positions in a pair of homologues, were tested in order to determine the frequency of loss of *Spm* from the female germ cells. It was found to be absent in approximately 6 to 10 per cent of the female gametes produced by these plants. The majority of such losses of *Spm* occurred late in the development of the germinal tissue.

In addition to the tests just discussed, an extensive series of tests was also conducted with each of eight distinctly different states of a_1^{m-1}. This was done in order to examine the mode of control of change in gene action at A_1 exhibited by each state in the presence of *Spm*, to discover the type of gene action appearing in its absence, and to determine the stability of each state—that is, its constancy—in the presence of *Spm*. Also, several of the states were combined in a single individual, and the independence of action of each in the presence of *Spm* was determined. Allelic relationships of states were revealed by segregation ratios in the progeny of these individuals.

The states of a_1^{m-1} *and their significance.* From an examination of the various states of a_1^{m-1} it has been possible to learn about the modes of control exerted by this a_1^{m-1}-*Spm* system on mutation types, frequencies of occurrence, and times of occurrence during the development of a tissue. Control of all these resides in the element located at A_1, and this is not influenced by the number of *Spm* elements that may be present, although *Spm* is required for the manifestation of these controlled types of expression. Seven of the eight different states that have been studied were isolated after a change that occurred in the element originally introduced at the A_1 locus. This original state of a_1^{m-1} gives rise, in the presence of *Spm*, to many early-occurring mutations, both in the plant tissues and in the aleurone layer of the kernel. The intensity of pigmentation these mutations produce ranges from faint to deep. A number of germinal mutations also occur, and these give rise to alleles that are stable in the presence of *Spm*. When plants having this state of a_1^{m-1} are crossed with plants homozygous for a_1, kernels on the resulting ears will occasionally show a decidedly modified pattern of mutation. The kinds of mutation may be altered, or their frequency of occurrence may be different, or their times of occurrence may be shifted; or combinations of these several identifiable alterations of expression may appear in such kernels. Some of these kernels were removed from ears, and plants were grown from them. These plants, in turn, were examined to determine the behavior of a_1^{m-1} in them. It was found that in the presence of *Spm* the pattern of mutation appearing in the kernel from which the plant arose reappeared in the following generation. In other words, the alteration at a_1^{m-1} responsible for the changed pattern of mutation was maintained in chromosome reduplication and thus was heritable.

A description of several of the derived states may be used to illustrate the range of their expressions. One state produces, in the presence of *Spm*, only a relatively few dots of color in an otherwise colorless kernel, but these dots are intensely pigmented. The plants also show only a few small streaks of deep pigmentation in a nonpigmented background. In the absence of *Spm*, the plants are darkly pigmented but the kernels are only faintly colored, and these expressions are constant in successive generations as long as *Spm* is absent. When *Spm* is returned to the nucleus, the pattern of expression described above again appears—a few dots of deep pigmentation in a colorless background in the kernel and

a few streaks of deep pigmentation in the plant. Only very rarely does this state of a_1^{m-1} give rise to a mutation in a germinal cell, and no subsequent change of this state to another state has yet been identified.

Another state, derived from the original one, is somewhat similar to that just described in its behavior in the presence of *Spm*. In the kernels, dots of deep color appear in a colorless background, but their number is larger. On an occasional kernel, a large deeply pigmented spot may also be present. The plants having this state show a number of fine streaks of deep pigmentation in a nonpigmented background. In the absence of *Spm,* however, this state is readily distinguished from the one just described, for now both the kernels and the plants are intensely pigmented. Return of *Spm* to the nucleus brings back its suppressor action and calls forth the pattern of mutation characteristic of this state. Few germinal mutations occur, and changes of this state to another state are rare.

Still another state gives rise to dots of deep color in the presence of *Spm,* but these are so numerous that the kernel appears almost solidly colored when viewed from a distance. The plant also shows numerous small streaks containing anthocyanin pigment. Only a few germinal mutations occur. In the absence of *Spm,* the kernels are lightly but distinctly pigmented, and the plants are also pigmented. Another state gives rise, in the presence of *Spm,* to many early-occurring mutations, and these express the higher levels of pigment intensity. Many germinal mutations occur. In the absence of *Spm,* the kernels having this state are lightly pigmented and the plants also are pigmented. In this case, as with all states so far examined, return of *Spm* by appropriate crosses in some succeeding generation will call forth the pattern of mutation characteristic of the state.

One state differs from all others with respect to the types of mutation it produces. In the presence of *Spm,* the mutations may occur early in development. In the kernels, the colored patches, representing mutant areas, show low levels of pigment intensity. Only very rarely, indeed, does a colored patch appear that expresses the standard A_1 phenotype. Many germinal mutations occur, and among the kernels having them the same low levels of pigment intensity are shown. The plants derived from these kernels are pigmented, the intensity in each case corresponding to that shown by the kernel from which the plant arose. In the absence of *Spm,* the kernels having this state show either no color at all or only a very faint trace at their base. In the plants, also, no anthocyanin pigment is detected on visual examination.

By intercrosses, it is possible to combine two different states in an individual plant or kernel. When *Spm* is present, the mutation pattern produced by each of the states is evident, indicating the autonomy of each with respect to its mode of action. This is well illustrated in kernels having the state just described and also a state that gives only late-occurring mutations that are expressed in the kernel as deep-colored dots. Both patterns of mutation appear in these kernels: the pale-colored areas, many of which are large, produced by the former state, and the deep-colored dots produced by the latter. There appears to be no interaction between the states that affects their individual modes of expression. The autonomy of each state is also made evident by the ratio of types of kernels that appear on ears produced when plants having two different states of a_1^{m-1} are crossed to plants homozygous for a_1. The two states segregate from each other at meiosis, and a 1:1 ratio appears among the kernels.

Conclusions regarding the operation of the a_1^{m-1}-Spm system. The general mode of control of gene action and of mutation by this a_1^{m-1}-*Spm* two-element system is now evident. The element of this system that is inserted at the A_1 locus plays a major part in controlling gene action and

in effecting changes in such action, both in the presence and in the absence of the second element, *Spm*. The *Spm* element exerts a direct influence on the element located at A_1, in two distinctly different ways. First, in the absence of *Spm* some gene action occurs at A_1, but in its presence this is totally suppressed. Secondly, *Spm* induces modifications of the element residing at A_1 that do not occur in its absence. Two kinds of modification arise. One effects a stable mutation, and the mutants so formed give rise to a series of alleles that differ from one another both quantitatively and qualitatively. The second type of modification, of rarer occurrence, leads to a change in the controlling element at A_1—a change in state—that is subsequently discerned. In the presence of *Spm*, these modifications are expressed by changes in the kinds of mutations that occur, their frequencies of occurrence, and their times of occurrence during the development of the tissues. These modifications of state also affect the degree of action of the genic materials at the A_1 locus in the absence of *Spm*.

Spm may be transposed from one location to another in the chromosome complement, both in somatic and in germinal cells, without losing its specificity of action in the process. Thus, loss of *Spm* from some nuclei and increase in others may occur within an individual plant. An increased number of *Spm* elements in a nucleus is not made evident by changed patterns of mutation at a_1^{m-1}. This contrasts greatly with the case of the a_1-*Dt* system, where increase in number of *Dt* elements is made evident by increased frequencies of occurrence of mutation at the a_1 locus. It also contrasts with the behavior of *Ac* in the *Ds-Ac* system. With regard to a_1^{m-3} and a_1^{m-4}, both of which express control of mutation at A_1 by the *Ds-Ac* system, successive increases in number of *Ac* elements retard in a stepwise manner the time of occurrence of mutation at the modified A_1 locus in each case.

Knowledge gained from an examination of the mode of operation of this system of control of gene action and mutation, and a comparison with other systems operating at the very same locus, has greatly enlarged our appreciation of the probable significance of such systems in regulating gene action during development. Somatically occurring changes in gene action, both gross and subtle, can result from their operation, and these are well regulated with regard to both time of occurrence and type of change.

Continued Studies of the Mode of Operation of the Controlling Elements *Ds* and *Ac*

Several other projects were carried out during the year. Two of them were concerned with the elements *Ds* and *Ac*. The general mode of behavior of these two elements has been described in many previous reports. Although the tests conducted this year were many and the data obtained were extensive, only the most significant evidence and conclusions will be given here.

The first of these projects was an analysis of the direct control by *Ac* of change in gene action at the bronze (*bz*) locus in chromosome 9 when it is inserted there. It could be demonstrated that these changes are associated with events affecting the *Ac* element itself. They give rise to several different phenotypic expressions of the genic materials at the bronze locus: a stable recessive (*bz*) expression, a full dominant (*Bz*) expression, and an expression that is intermediate between these two extremes. Stability of the mutants depends on whether or not *Ac* is removed from the immediate vicinity of the bronze locus by the event that affects it and results in the change in genic expression. If it is removed, the mutant is stable in subsequent generations. If it remains, the mutant is unstable, in that subsequent alterations of *Ac* may lead to further change in action of the genic materials at the locus. The time of occurrence, during the devel-

opment of a tissue, of these mutation-inducing alterations of *Ac* depends on the total dose of *Ac* present in the nucleus: the higher the dose, the later they will occur. Such responses to *Ac* dose may be effected either by increasing the number of chromosomes 9 carrying *Ac* at the bronze locus—from 1 to 3 in the kernel and from 1 to 2 in the plant—or by adding *Ac* elements that are located elsewhere in the complement when only one chromosome 9 carries *Ac* at the bronze locus.

Some of these *Ac*-altering events at the bronze locus give rise to a dicentric chromatid and the corresponding acentric fragment. Changes in the frequency of occurrence of this type of event characterize some of the changes in state of *Ac*. One other modification was detected, and it is of general significance in considering interrelations that may arise between controlling elements. One kernel was found that showed a marked increase in frequency of occurrence of mutation to *Bz*. The tissues of the plant grown from it exhibited the same increased frequency. Tests of this plant revealed that an alteration had occurred at the bronze locus in a germinal cell of the parent plant, resulting in a modification of the mode of control of subsequent mutation. *Ac* was still present and was required for the occurrence of these mutations, but it was no longer located at the bronze locus in the short arm of chromosome 9. The mode of control now followed that which characterizes the *Ds-Ac* two-element system, in which the *Ds* element directly controls the change in gene action at the locus where it resides, and the *Ac* element governs the occurrence of these mutation-inducing events at *Ds*. It must be concluded, therefore, that this modification arose from substitution of a *Ds* element for the *Ac* element at the bronze locus; or that the *Ac* element originally inserted there is compound and may be separated into two components, a *Ds* and an *Ac* element; or, possibly, that a *Ds* element may originate from some modification of an *Ac* element. No evidence is now available to suggest which of these alternatives is most probable. Nevertheless, the observed change from a one-element to a two-element system of control of gene action and mutation is significant in considering the relations that exist between controlling elements and systems of such elements.

An additional project that received much study was concerned with the behavior of *Ds* after its insertion just to the left of Sh_1 in chromosome 9. In this position, it induces changes in action of genic substances located on either side of it, and these effects may include a segment of the chromosome six or more crossover units long in the standard chromosome 9. During the past year, several cases of extended modification of gene action, in which the genic components farthest removed from *Ds* exhibited reversion to standard expression, were examined. In all cases, it could be determined that the *Ds* element was a component of the segment of chromosome showing altered genic action, and that the reversions observed were accomplished by some change involving the *Ds* element itself. The patterns of reversion were those associated with the operation of the two elements, *Ds* and *Ac*: *Ac* was required for their occurrence, and the times of occurrence reflected the dose of *Ac* that was present in the nucleus. In the cases examined, the reversions to normal action of a genic component within the modified segment were not accompanied by loss of *Ds* or by change in its location. This is unlike the behavior of *Ds* at some other known loci. In these other cases, it has been determined that reversion of gene action is often accompanied by removal of *Ds* from the immediate vicinity of the locus concerned.

Many different tests have been made of the behavior of *Ds* when inserted just to the left of Sh_1, and all of them indicate that *Ds* is effectively fixed in location after its insertion there. It can continue, then, to exert its influence on the action of genic substances located to either side of it. Thus a sequential series of changes in action of

these genic materials can occur as long as *Ac* is also present in the nucleus, and a number of such sequences have been followed through three or more steps. The kinds of modification in gene action induced by *Ds* at this location resemble, in some respects, those appearing spontaneously at some other well-known gene loci in maize, such as the *R* locus, whose numerous alleles are known, as well as spontaneous rates of change to other alleles. It is possible that there is a controlling element or elements present at this locus, and also at other loci in the standard chromosome complement of maize, and that the modifications in gene action they induce are responsible for the appearance of the mutants and for the particular sequences of change from one type of allele to another that have been observed.

ORGANIZATION OF CELLULAR MATERIALS

B. P. Kaufmann, M. R. McDonald, H. Gay, C. Ghosh, A. Silberzahn, and K. Fuscaldo

During the past year our efforts have been directed toward analysis of organizational patterns of nuclear and cytoplasmic materials. Methods of descriptive and analytical cytology have been brought to bear on problems of the nature and specificity of gene action. The first, or descriptive, approach has been facilitated by use of the electron microscope. Exploratory studies with this instrument were outlined in Year Book No. 53, and more recent efforts have given tangible expression to our premise that electron microscopy offers enormous potentialities for analysis of genetic reaction systems. The second, or analytical, approach has utilized the cytochemical methods developed in this laboratory for identification and localization of cellular materials. Both approaches have yielded new and important information about cellular "differentiations" at the "submicroscopic" level. Immediately before us lies the prospect of combining these two methods so that electron microscopy may be used in the examination of tissues that have been "dissected" with enzymes or subjected to other experimental procedures. Preliminary experiments along these lines have recently been undertaken, and they are briefly summarized in this report.

In developing this program we have utilized to a considerable extent the facilities available in neighboring institutions. The electron micrographs used by Gay in studies of nucleo-cytoplasmic interrelations were made with the Philips electron microscope at the Rockefeller Institute for Medical Research; we are deeply grateful to Dr. Keith Porter for the privilege of using this instrument and other equipment in his laboratory. Micrographs used in other studies were made with the RCA electron microscope at the Brookhaven National Laboratory; we wish to express our thanks to Dr. Howard J. Curtis, Director of the Biology Department, and to Dr. Donald Fluke for their personal interest in making this instrument available.

From time to time throughout the year we have employed temporary assistance. Workers who have served on this basis include Sydney Smith, Suzanne Hume, Sara Terry, and Anders Kaufmann. John Aronson, from the University of Rochester, and Marcus Hairston, from the University of Pittsburgh, joined the group during the summer of 1955 to work on special problems related to their graduate studies.

Our program has again been facilitated by a research grant (RG-149) from the National Institutes of Health, U. S. Public Health Service.

Electron Microscope Studies

Efficient use of the electron microscope in analysis of the materials of heredity depends on the two technical developments reported in Year Book No. 53, namely, the method of preparing and mounting ultrathin serial sections, and the method of imbedding smears of chromosomes (or isolated cells) in methacrylate resin preparatory to sectioning. Application of these methods has afforded substantial in-

formation with respect to three problems that have long been subjects of controversy among cytologists and geneticists: the structure of the salivary-gland chromosome of the dipteran larva, the structure of the nuclear membrane, and the mechanism of nuclear control in production of cytoplasmic organelles.

Structure of the salivary-gland chromosome. Of the various theories of structure of the salivary-gland chromosome based on observational evidence obtained with the light microscope, the most satisfactory assumes the existence of a system of extended and closely appressed chromonemata. Objections have been raised to this theory, however, on the grounds that the longitudinal striae observed may represent merely surface artifacts induced by spreading and fixing, and that the chromonemata, if they actually exist, must be of submicroscopic dimensions. Recent spectrophotometric studies of salivary-gland chromosomes at various stages of development have indicated that the amount of deoxyribonucleic acid (DNA) increases by a series of doublings until in the late third-instar larva it is about 1000 times the amount present in an actively dividing cell. These findings seem to provide further evidence of the polytene, or many-stranded, nature of the salivary-gland chromosome. Gay has now obtained additional evidence in support of the multiple-strand interpretation, from a study of electron micrographs of salivary-gland chromosomes of *Drosophila, Sciara,* and *Chironomus,* and has been able in addition to determine the approximate diameters of the component strands and their patterns of association.

Electron micrographs of ultrathin sections of smears and intact nuclei indicate that the salivary-gland chromosome is composed of a number of closely appressed chromonemata, each of which is divided into chromomeric and nonchromomeric regions. Lying in juxtaposition, the chromomeres constitute the bands; the nonchromomeric intervals form the interband regions. Reconstruction of serial sections has revealed that the component chromonemata are not arranged in the way originally visualized, however, as rows of straight, parallel threads, but are coiled in pairs to form a hierarchy of coiled pairs constituting the coiled homologues. The smallest units, which are the most recently formed chromonemata in this system, are about 500 A in diameter and therefore lie below the limits of visibility afforded by the ordinary light microscope, although they are detectable with the electron microscope. Comparison of diameters of individual chromonemata and of their distribution within a section of the entire chromosome indicates that the number of component strands is between 1000 and 2000 (probably either 2^{10} or 2^{11}). The bands of the chromosomes are conspicuous because the component chromomeres consist of material that is more highly electron-scattering than the material of the interband regions (pl. 1A). Irregularities

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PLATE 1

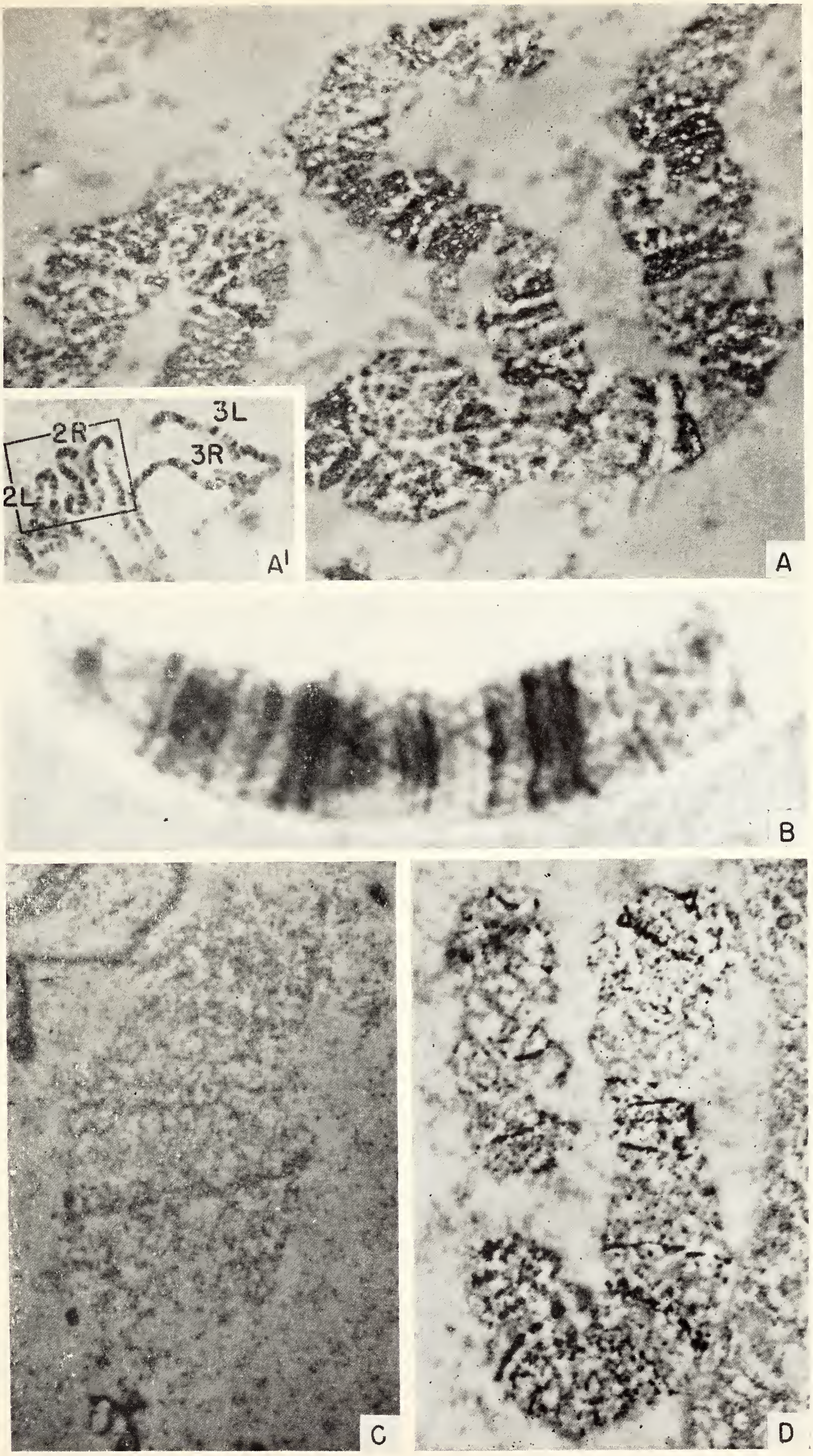
A. Electron micrograph of an ultrathin section of an aceto-orcein smear of salivary-gland chromosomes from a third-instar *Drosophila melanogaster* larva. × 6600.

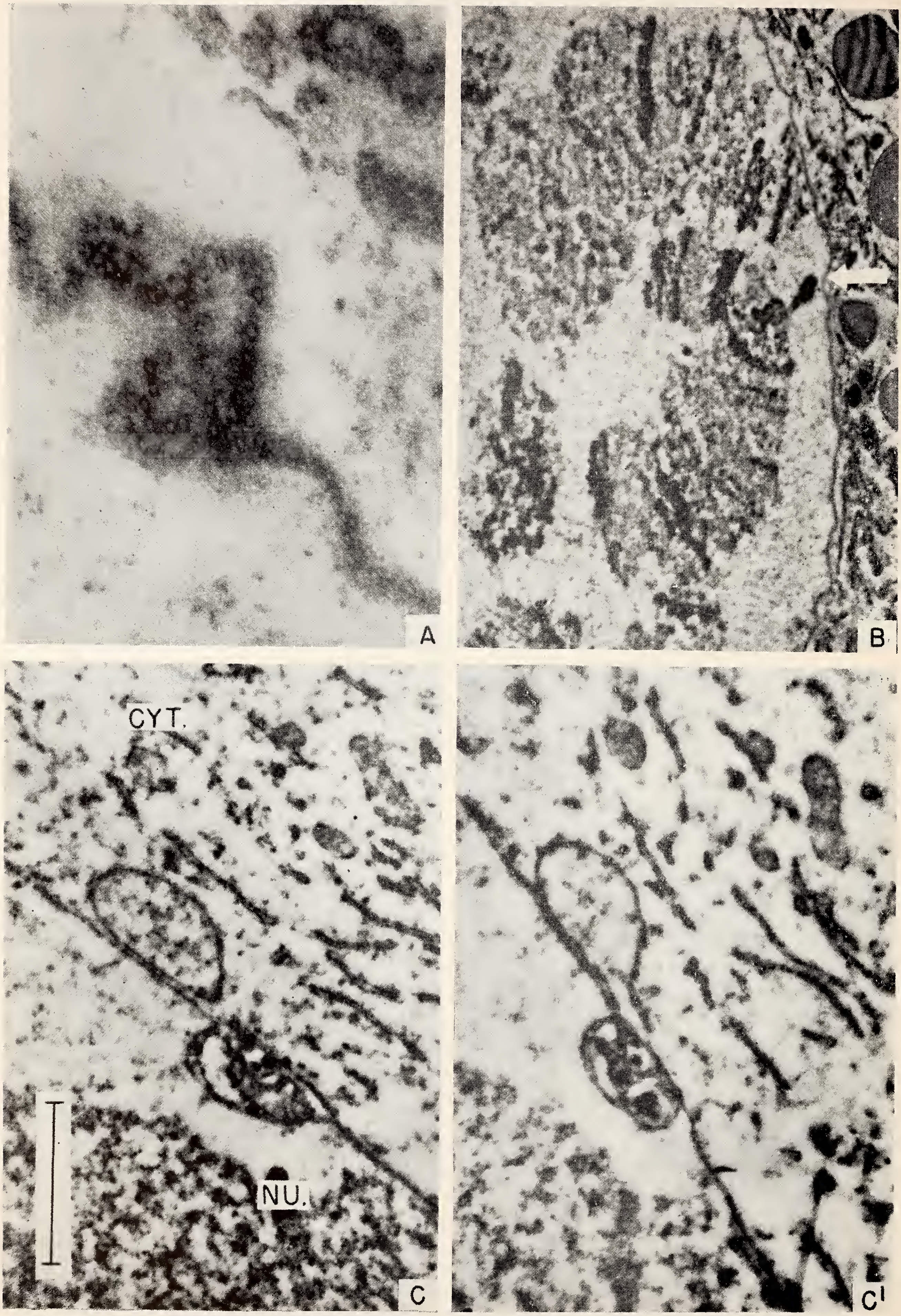
A′. Light-microscope photograph of the unsectioned methacrylate-imbedded smear. The individual chromosomes may be located in this view to facilitate identification in the electron micrograph (A).

B. Section of a chromosome of *Chironomus* sp. salivary gland fixed in Benda's fluid and imbedded in paraffin. This light-microscope photograph is one of a series taken at different focal levels, showing the intertwined chromonematic strands of the paired homologues. × 2900.

C. Electron micrograph of an ultrathin section of a chromosome from a *Drosophila* salivary-gland cell fixed in 1 per cent buffered osmium tetroxide, pH 6.5. × 13,300.

D. Electron micrograph of an ultrathin section of a chromosome from a *Drosophila* salivary-gland cell fixed for 5 minutes in 1 per cent buffered osmium tetroxide and then treated for 5 minutes in 45 per cent acetic acid. The bands appear much more dense than in C. × 5100.


3L
2R
3R
2L
A'
A
B
C
D


A
B
CYT.
NU.
C
C'

in the structure of the bands were observed in these studies, as they have been in many earlier studies; these are attributed to dispersion of the material that constitutes the chromomeres, perhaps in the course of fixation.

How does this interpretation accord with the observations described in Year Book No. 51, in which salivary-gland chromosomes preserved by Anderson's critical-point method showed a coarsely fibrous pattern and relatively few component strands? (See also pl. 1B.) It is now apparent that these coarse strands must represent aggregates of chromonemata. Further evidence in support of this view has been obtained by Gay in a comparative study of the effects of different fixatives. Some, such as acetic acid or acetic acid–alcohol, tend to precipitate the structural components of the chromosome into fibrous aggregates (pl. 1D), whereas others, such as buffered osmium tetroxide, preserve more adequately the identity of the individual component strands (pl. 1C). It should be noted, however, that the coarse patterns are not merely artifacts induced by stretching the chromosomes in the course of smearing, and cannot be regarded solely as surface patterns; coarse and fine detail have been observed in sections of intact cells as well as in sections of smears (pl. 1B–D).

One additional observation is noteworthy. No membrane was detected bounding or limiting the chromosomes in any of the preparations studied. It is therefore concluded that the salivary-gland chromosome has no such membrane. This finding suggests that the chromosome cannot be a highly hydrated system such as might result from imbibition of water by the two primary strands of each homologue, as some workers have proposed. Increased size without a limiting membrane implies accumulation and perhaps change of state of nucleoproteins in the course of growth, as might be expected on the basis of multiplication of chromonemata. The absence of a limiting membrane on the chromosome should facilitate nucleo-cytoplasmic exchanges such as will be discussed in a later section of this report.

The nuclear membrane. In contrast with the individual chromosomes, the nucleus of the salivary-gland cell has a membrane of definite structural properties and detectable dimensions. Gay has shown this clearly in electron micrographs of third-instar larvae of *D. melanogaster* (pl. 2A).

In tangential sections the nuclear membrane reveals a reticulate structural pattern. Highly electron-scattering material (apparently granular) surrounds, and sometimes extends between, less electron-dense areas (called pores by some workers), which appear circular, hexagonal, or pentagonal in outline and are about 500–600 A in greater diameter; they are spaced approximately 1000 A from center to center. Some of these areas show in the center a denser, dotlike structure. In cross sections it can be seen that the nuclear membrane is composed of two thin layers of densely absorbing material with occasional discontinuities, separated by material of lesser absorbing capacity, the total thickness being about 250 A. At intervals the two electron-dense layers can be seen to fuse with each other. It is suggested that these fu-

PLATE 2

A. Electron micrograph of a tangential section of the nuclear membrane of a salivary-gland cell of *Drosophila*. × 31,300.

B. Ultrathin section of a part of a *Drosophila* salivary-gland nucleus, showing highly electron-scattering material (arrow) associated with a band within a "reverse repeat," presumably heterochromatin. Serial sections adjacent to this one indicate that the dense material is in contact with the nuclear membrane at a place where an outpocketing occurs. × 9300.

C, C′. Electron micrographs of two sections, selected from a complete series, showing a large flasklike outpocketing of the nuclear membrane. Note the structural detail within the associated nuclear material. The marker in the lower left-hand corner of C indicates one micron. × 24,000.

sions contribute to the reticulate pattern seen in tangential sections of the membrane.

In general, these observations are in accord with the conclusion reached by others (especially Bahr and Beermann with respect to *Chironomus*) that the nuclear membrane of larval dipteran salivary-gland cells consists of parallel layers of densely absorbing material. The German workers have interpreted the discontinuities in the membrane as pores, but this interpretation must be accepted with caution. The presence of the dotlike material in the center of the "circular" areas of the *Drosophila* nuclear membrane suggests the possible existence of a structural pattern analogous to that of the bordered pit in the walls of tracheids of the gymnosperms. In that case, there would be a continuous supporting membrane across the "pore"; this interpretation would be more readily reconcilable with available information about membrane permeability than would the assumption of the existence of a sievelike membrane. There are many other possible interpretations, which cannot be evaluated until additional experimental work has been completed.

Nucleo-cytoplasmic interrelations. Theoretical considerations of nucleo-cytoplasmic interrelations have been advanced by biologists since De Vries presented his hypothesis of intracellular pangenesis in 1889, but the supporting cytological evidence has been derived for the most part from a series of observations of cytoplasmic particles assumed to be of nuclear origin. The essential role of the nucleus, and indeed of individual component chromosomes, in sustained control of metabolic activities of the cell has long been recognized; what was lacking was a clear demonstration of a mechanism whereby the chromosomes, or specific regions thereof, participate in the exchange of materials between nucleus and cytosome. Such a mechanism has been discovered by Gay in the salivary-gland chromosomes of *Drosophila.*

Salivary-gland cells of the late-third-instar larva of *D. melanogaster* are involved in the production of a secretion (apparently a mucoprotein) that ultimately serves, on ejection by the larva, to anchor the puparium to the substrate. In electron micrographs the nuclear membrane of these cells was seen to be undulous, extending in some places into the cytosome as pronounced outpocketings (pl. 2C, C′). A series of tests, involving a variety of fixing fluids, has indicated that these outpocketings are characteristic structural features and not merely fixation artifacts.

The outpocketings are not uncommon in these cells, and have invariably been found in association with dense chromosomal materials. In many cases the chromosomal strands extend into the outpocketings. Examination of serial sections in which an outpocketing could be traced in its entirety have revealed connections with the salivary-gland chromosomes. In some cases the connections were to single bands in intercalary regions, and in others apparently to terminal chromatin. Occasionally the intercalary band was located in a "reverse repeat" (pl. 2B), and although no positive identification has been possible in the ultrathin sections with respect to the specific subdivisions of chromosomes involved, it may be noted that reverse repeats frequently indicate the location of intercalary heterochromatic regions (Year Book No. 43, 1943–1944).

Observations on static systems such as those represented in sections of fixed materials have limitations with respect to the interpretation of functional relationships; but the intimate association between chromosomal materials and membrane outpocketings suggests a mechanism for transfer of chromosomal products to the cytosome. Further studies of the phenomenon have led to the suggestion that the blebs become detached from the nucleus to lie in the cytosome. It will be recalled from the foregoing discussion that the nuclear membrane is two-layered. Membranes in the cytosome adjacent to the nuclear membrane are also two-layered. They reveal,

moreover, the same patterns of sculpturing that are seen in the nuclear membrane. This similarity suggests that the blebs, freed from their connection with the nuclear membrane, become flattened to form the saclike membranes of the so-called endoplasmic reticulum. The electron micrographs suggest, in addition, that the secretion granules in the cytosome arise in close association with the lamellae of the reticulum. A mechanism is thus disclosed whereby specific chromosomal regions may participate in the production of metabolically active cytoplasmic organelles. Although the mechanism has been inferred from observations of one type of cell at a particular stage of development, the genetic implications are of sufficient general interest to warrant further consideration.

Detachment of parts of the nuclear membrane and their release into the cytosome represents a unique feature, which had not been considered in earlier theoretical discussions of nucleo-cytoplasmic interrelations. Schultz suggested in 1951 that the properties of the nuclear membrane may vary according to the chromosomes involved in its production, and that this variation may afford a basis for differential cell function and cell differentiation. Gay's findings not only sustain this point of view, but extend the concept to include a nuclear membrane whose properties are not irrevocably fixed at the time of cell division, but which is capable of continuous displacement and re-formation in the metabolically active cell. Basic problems concerned with differentiation and dedifferentiation, with the origin and location of cytoplasmic organelles and "plasmagenes," and with more general aspects of the eventuation of phenotypes are thus brought into clearer focus. It would be hazardous indeed to imply that the proposed mechanism is anything more than one of a possible series of alternative methods by which these end results may be mediated. Nevertheless, the importance of these findings lies in the fact that they represent the first tangible demonstration of a mechanism for nuclear control over cytoplasmic function, and introduce new bases for more meaningful experimental attacks on problems of gene action. A fuller evaluation of these implications has been prepared by Gay and Kaufmann for publication elsewhere.

Cytochemical Studies

Release of deoxyribonuclease from roots growing in solutions of ribonuclease. Crystalline enzymes were used originally in our cytochemical studies to determine the patterns of association of nucleic acids and proteins in fixed tissue sections (Year Books Nos. 46–53), and have been employed more recently in treatment of living cells. The studies in which ribonuclease was used to produce mitotic abnormalities in growing root tips (Year Books Nos. 51–53) have been extended by other workers, and form the basis of current investigations by Brachet and his group at Brussels and by Ledoux in London. More recent experiments in this laboratory by Kaufmann and Ghosh have been concerned with the patterns of cellular organization revealed by the action of ribonuclease on growing roots.

Solutions of ribonuclease in which onion roots were growing acquired the capacity to degrade DNA in fixed tissue sections, as evidenced by reduction of stainability of the chromosomes with orcein, methyl green, or the leucobasic fuchsin of the Feulgen procedure. None of the controls, including ribonuclease that had not been used in treatment of growing roots, produced comparable degradation of chromosomal materials in fixed tissues when used under similar experimental conditions. These results indicate that ribonuclease enters the growing root, where it effects alterations in cellular materials that lead to the loss of deoxyribonuclease from the cells and—as our original studies had indicated—the production therein of mitotic abnormalities.

The deoxyribonuclease released from the roots is similar to that obtained from root

homogenates with respect to the conditions of pH and temperature that favor activity (Year Book No. 52); and it is probably the same enzyme. It is capable of hydrolyzing isolated DNA, but not capable of hydrolyzing intracellular DNA unless the cells have previously been treated with ribonuclease, as was clearly demonstrated in studies of the homogenate deoxyribonuclease. This dependence affords a basis for considering the patterns of association of DNA and ribonucleic acid (RNA) in the living cell. An evaluation of various alternatives has led to the conclusion that the chromosomes contain an RNA-DNA complex, in which the DNA cannot be degraded by the onion-root deoxyribonuclease until after the RNA has been removed.

The action of ribonuclease in releasing deoxyribonuclease from growing roots may involve either modification of the properties of the cell surface or degradation of an intracellular (cytoplasmic) RNA-deoxyribonuclease complex. The latter seems more probable on the basis of evidence reported for other organisms. Under such conditions RNA might serve as an inhibitor of the enzyme, controlling its intracellular activity with respect to deoxyribonucleotide metabolism. The fact that cytoplasmic RNA is located primarily in the microsome fraction (which is produced, according to Palade's recent findings, from the endoplasmic reticulum) shows how closely the genetic implications of Gay's electron-microscope studies are related to specific problems of cellular metabolism.

The action of hemoproteins in altering cellular basophilia. During the course of these investigations it was noted that treatment of sections of fixed onion root tips with cytochrome c resulted in a marked decrease in the capacity of the sections to stain with basophilic dyes, such as pyronin or azure B, and an increase in their capacity to stain with acidic dyes, such as fast green. No effect on Feulgen or methyl green stainability appeared. Analysis of this action of cytochrome c was undertaken this year, with all members of the group participating, but it has not yet been possible to make a clear-cut decision about the mechanism involved.

As was noted in Year Book No. 53, the modification of tissue stainability by cytochrome c might be a nonspecific effect due to combination of this basic protein (isoelectric point, 10.7) with cellular RNA. Other proteins were therefore studied. Lysozyme, trypsin, chymotrypsinogen, and hemoglobin (whose isoelectric points are, respectively, ca. 10.8, 10.5, 9.5, and 6.8) increased stainability with the acidic dye fast green in tissue sections treated with these proteins at pH 6; egg albumin and serum albumin (isoelectric points, 4.7 and 4.4) did not. On the other hand, only the two hemoproteins, cytochrome c and hemoglobin, reduced stainability of the tissue sections with the basic dyes pyronin and azure B. It is evident that combination of basic proteins per se with cellular RNA is not the primary factor in reducing basophilia, although, as shown in the "test tube" and in treatment of fixed spots of isolated RNA, combination of basic proteins and RNA undoubtedly takes place at pH 6 and may account for the increased stainability of tissue sections with acid dyes when treated with basic proteins.

Spectrophotometric data bearing on this question were obtained during the summer of 1955 by John Aronson, using our Bausch and Lomb Grating Monochromator in conjunction with ultraviolet-transmitting optics (the B. & L. reflecting objective, condenser, and quartz ocular) in analysis of sections of root tips treated with the above-named substances. These data have confirmed the findings reported in the preceding paragraph, and have added the pertinent fact that with cytochrome c and hemoglobin, but not with lysozyme, there is, concurrently with the reduction in pyronin stainability (wave length, ca. 550 mμ), a reduction in absorption in the ultraviolet range corresponding to "loss" of purines and pyrimidines (wave length,

ca. 260 mμ). This is illustrated in figure 8. That cytochrome c and hemoglobin, or at least their heme components, are adsorbed by the tissue sections is evidenced by the increased light absorption noted at 404 mμ in sections treated with these proteins. Further experiments are in progress to determine the mechanism whereby treatment of fixed tissue sections by the hemoproteins, cytochrome c and hemoglobin, brings about reduction in their ultraviolet absorption in the nucleic acid region of the spectrum.

Specificity of pancreatic ribonuclease in hydrolyzing cytidine-2′:3′-phosphate. It has been demonstrated in several laboratories that hydrolysis of RNA by crystalline pancreatic ribonuclease occurs in at least two stages. There is an initial *rapid* depolymerization of the nucleic acid, accompanied by the formation of cyclic 2′:3′-phosphates of pyrimidine nucleotides, and a subsequent *slow* hydrolysis of these cyclic compounds to the free nucleotides. Ribonuclease has also been found to degrade polyribophosphate and apurinic acid, and it has been suggested that it is the absence of purines rather than the presence of pyrimidines that determines the specificity of pancreatic ribonuclease. We have shown, however, as noted in Year Book No. 53, that the degradation of apurinic acid by ribonuclease is a nonspecific function of the enzyme, other basic proteins such as lysozyme and cytochrome c being equally effective. This, together with the finding of Kalman, Linderstrøm-Lang, Ottesen, and Richards that the depolymerizing action of ribonuclease and its action on the cyclic phosphates do not disappear simultaneously when this enzyme is hydrolyzed with subtilisin, raised the question whether the *slow* hydrolysis of the cyclic phosphates by ribonuclease might not also be a nonspecific property of the enzyme. This problem has been

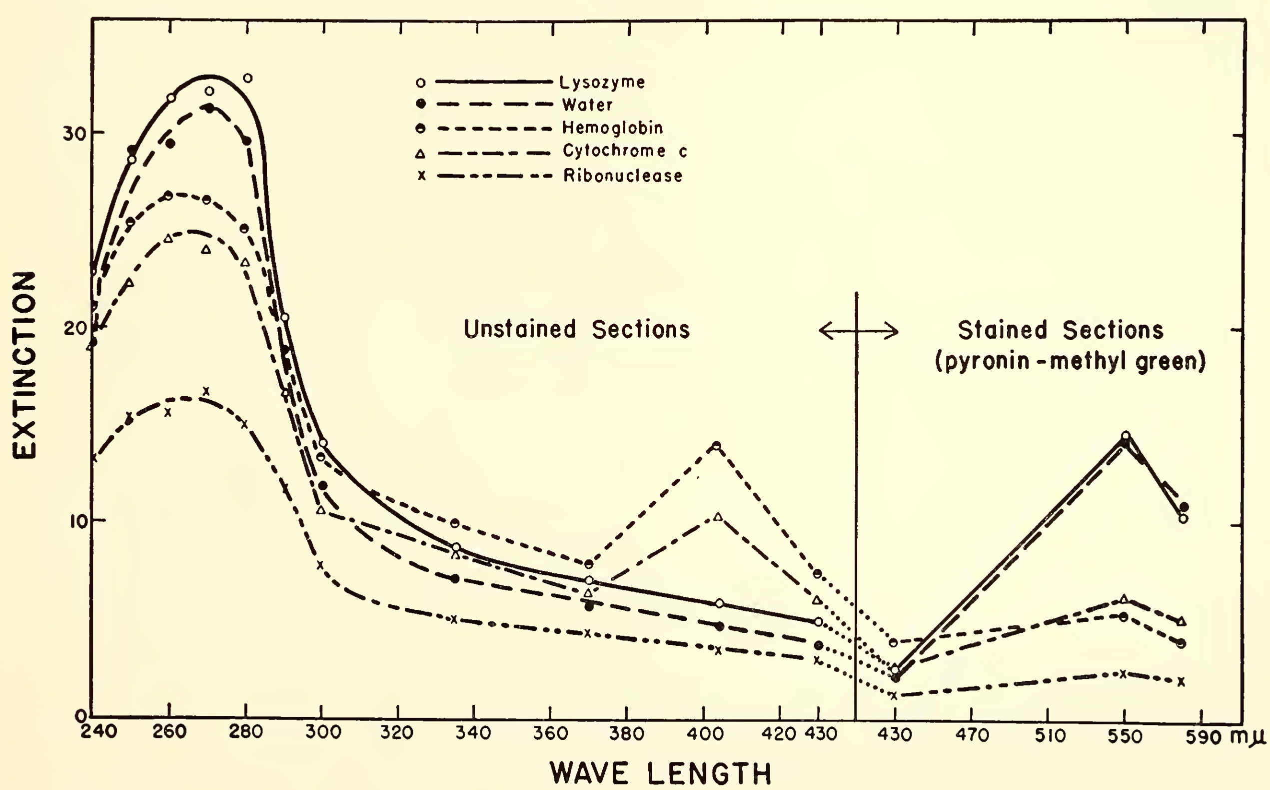


FIG. 8. Absorption spectra of sections of onion root tips after treatment with aqueous solutions of various proteins. Absorption at 260 mμ is due mainly to nucleic acids, absorption at 404 mμ to the heme component of cytochrome c and hemoglobin, and that at 550 mμ to pyronin-stained materials (primarily RNA). Concentration of proteins, 1 mg/ml; time of treatment, 2 hours; temperature, 37° C; pH, 6.0. Difference in absorption of unstained and stained specimens at 430 mμ is probably attributable to the mounting media used: glycerine for the unstained, Bioloid for the stained.

investigated during the past year by McDonald.

Mixtures of solutions of cytidine-2′:3′-phosphate (final concentration, 8 mg/ml) with solutions of ribonuclease, lysozyme, or cytochrome c (final concentration, 0.1 mg/ml), or with water, were incubated at pH 7.5 and 37° C for 24 hours. Aliquots were then analyzed by paper chromatography for cytidine-2′:3′-phosphate and for cytidylic acid. It was found that only ribonuclease effected conversion of the cyclic phosphate to cytidylic acid. It appears, therefore, that the hydrolysis of the cyclic 2′:3′-phosphates of pyrimidine nucleotides by ribonuclease is a specific property of this enzyme.

Calf-spleen deoxyribonuclease. Many enzymes (deoxyribonucleases) capable of hydrolyzing DNA occur in various cells, although only the digestive one of bovine pancreas has been highly purified and crystallized. In some properties these enzymes are similar, but in others they are markedly dissimilar. For example, as reported in Year Book No. 51, onion roots contain a deoxyribonuclease which, unlike the pancreatic one, does not degrade the intracellular DNA of fixed cells unless they have first been treated with ribonuclease. Similar results have been obtained with deoxyribonuclease from calf spleen. A direct comparison of the modes of action of the diverse deoxyribonucleases cannot be made, however, until they have been isolated and purified.

Experiments were therefore initiated, as reported in Year Book No. 52, to develop procedures for the isolation, purification, and crystallization of calf-spleen deoxyribonuclease. These studies have been continued during the past year by McDonald and Silberzahn. Because of the low yields of the partially purified preparations (less than 4 g from 10 kg of spleen), and the advisability in enzyme-purification studies of having large quantities of material on hand at each step in the purification process before proceeding to the next step, much of their effort this year has been devoted to accumulating a stockpile of partially purified material. Although a considerable degree of purification of the enzyme has been effected, crystallization has not been achieved, and the best preparations to date are still contaminated with ribonuclease and proteolytic enzymes.

During one stage of the purification process a marked change was observed in the kinetics of degradation of DNA by the preparations concerned. At least two explanations are possible, namely, that more than one enzyme is involved, or that inhibitors of the reaction are being removed by the purification procedures. This aspect of the problem is now being investigated.

Retention of activity by solutions of pancreatic deoxyribonuclease after freezing and thawing. Deoxyribonuclease is a relatively scarce and expensive enzyme and is generally used cytochemically in very low concentrations. The accuracy attainable in weighing small fractions of a milligram is not very great unless sensitive microbalances are available; and replication of experiments becomes difficult under such conditions. In an attempt to circumvent this difficulty, Ghosh has carried out a series of experiments involving freezing and thawing of solutions of the enzyme.

Solutions containing 1.25 mg of enzyme per ml of 0.003 M $MgSO_4$ were placed in small, sealed containers in a deep-freeze cabinet at a temperature of about −20° C. They were stored at this temperature for periods ranging from 15 minutes (after freezing had occurred) to 35 days. On removal, each sample was thawed to about 4° C, diluted 1000-fold with 0.003 M $MgSO_4$, and then tested for its capacity to reduce Feulgen stainability in sections of onion root tips.

No appreciable loss in enzymatic activity resulted from the freezing-thawing process. The method is recommended for experimental procedures extending over a period of days in which a constant and uniform supply of enzyme of known potency and specificity of action is required.

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DEPARTMENT OF ARCHAEOLOGY

Cambridge, Massachusetts
H. E. D. POLLOCK, *Director*

The year covered by this report saw the completion of a program of field activities initiated in 1951. As is known from previous reports, these activities have been concerned with the peninsula of Yucatan. Major excavations have been carried out in the large pre-Columbian city of Mayapan, and archaeological surveys combined with lesser excavations have been advanced in a number of other locations and areas within the peninsula, notably along the east coast and in the Tabasco-Campeche region. This phase of our program is ended. There remains the task of studying the large collections of objects and the mass of data that are the products of this work.

It may be of some interest to those who have never been immediately in touch with archaeological field work to have some idea of the size of an operation such as ours that has extended over several years. Approximately half a million pieces of pottery, varying in condition and size from whole jars to scraps no bigger than one's fingernail, have emerged from the digging. Each single piece has passed through the hands of at least one person and usually of several people. By far the greater part of this material is classified and recorded; even the fragments so weathered as to elude classification are counted and a record is made of their provenience and association with other pottery and materials. Lesser artifacts—tools, ornaments, and the like, of stone, bone, antler, shell, coral, metal, pottery, stucco, even fragments of textile—have been catalogued to the number of 1400 specimens. Nor does this give a complete picture of the amount of such materials, for several objects are sometimes grouped under a single specimen number, and the cataloguing is not yet complete. Brief description, measurement, a rough sketch are the minimum of data that go with each specimen. Skeletal remains, human and animal, the former to be measured and studied, the latter to be identified, are to be numbered by the boxful. Stone sculptures, architectural and monumental, are recorded by the hundred. This list is by no means complete—for example, there are page upon page of architectural drawings—but it suggests the amount of material that is dealt with. These are the products of excavation. With their appearance above ground and their initial recording, the task of the archaeologist is only fairly begun.

In the course of our several field seasons at the large ruins of Mayapan, our work has proceeded along two main avenues of approach, namely, surface survey and excavations of varying magnitude at selected locations. Because of the great number of building remains within the city wall, only a small fraction of which we could hope to excavate within the time allotted to our program at this site, survey work took on particular significance, a significance amplified by our interest in the simple dwellings that make up so large a proportion of the remains. It was not, then, until the end of the 1954 season that our program of surface examination stood virtually completed. This situation allowed us to devote almost complete attention to excavation during the 1955 season. It further allowed us to judge what lacunae existed in our work up to that point, and where we might most profitably direct our efforts during our last season at Mayapan.

As can well be imagined, there were numerous situations that seemed to merit further investigation, and there were a number of problems the solutions of which held promise of providing worth-while knowledge. It appeared quite clear, how-

ever, that our work should give primary attention to two classes of remains. We needed a better sample of excavated house mounds than we had been able to obtain up to that time, showing the various types of structure and their distribution within the city. We also wished more knowledge of a class of buildings that at first had been thought to be civic or religious in function, but which further knowledge had given good reason to believe were the residences of the aristocracy or nobility. Most of our effort was kept within these two areas during the past season.

Ruppert and A. L. Smith, who carried the chief burden of surface survey at Mayapan, undertook widespread excavations in simple house mounds. They also worked in some of the larger structures of the second class mentioned above. The data they have accumulated must of course undergo careful study before they are interpreted. A factual statement of their findings appears in a following section of this report. One of the most promising aspects of their work was the complete excavation of several house groups. It is hoped that excavations of this sort will lead to some understanding of the pattern of residence in the extended family and will throw some light on the organization of domestic life within the group. As it seems quite clear that household worship was an important part of Maya culture at this time, there is also the question of how religion functioned within the family group.

One of the most imposing assemblages of buildings at Mayapan is the large quadrangle partly excavated this season by Proskouriakoff and Temple, the latter a graduate student in anthropology at Yale University who worked with this Department during the field season. This quadrangle, which encloses a sizable courtyard, seems clearly to have been residential and very probably merits the often misused term "palace." The group is too large to have allowed complete excavation, but sufficient exploration was carried on to gain an excellent idea of the growth and development of the complex. There is good reason to believe that it was planned from the beginning to be a residence. Although there was continual tearing down, rebuilding, renovation, and general change of plan, it is surprising to discover that the complex was begun at a late date in relation to the main ceremonial center of the city. This relative lateness appears to characterize many of the residences we have tested, and this fact raises some interesting problems in regard to the growth of the city. Like many other structures, the quadrangle seems to have been occupied at the time of the violent destruction of Mayapan, for many objects, apparently left by the departing inhabitants, were found on the floors of rooms beneath debris from the burned roofs. An interesting discovery was a kitchen that retained a number of its furnishings, with other household articles and a deep deposit of midden refuse off the slopes of the terrace outside the room. It was not until this season that any kitchen had been identified. The removal of valuables, as witnessed by the looting of caches, was prevalent in the quadrangle as in many other buildings we have excavated, but a new light on the behavior of a presumably fleeing group of people was provided here through the discovery of a tremendous number of effigy incense burners dumped into a plundered tomb, as though the household gods had better be broken and buried than allowed to fall into the hands of people of alien beliefs. It is possible that the breaking occurred at the hands of the alien group, but there are indications that it was done by the departing residents of the palace.

A residential group almost as imposing as that referred to above was excavated by J. E. S. Thompson and D. E. Thompson, the latter a graduate student in anthropology at Harvard University, working with this Department. A discovery of particular interest was a cremation, sealed within a pottery jar, buried in the altar of what appeared to be the family oratory. As is pointed out by Thompson and

Thompson in a succeeding section of this report, this cremation strongly suggests a cult of ancestor worship such as that described by Bishop Landa.

Although our excavations this past season were primarily directed toward gaining knowledge of the domestic side of Maya life—additional work of this sort being carried on by Chowning, a graduate student in anthropology at the University of Pennsylvania, temporarily with this Department, and by D. E. Thompson—some effort was also directed toward amplifying our knowledge of the civic and religious aspects of the culture. Pollock undertook limited excavations at a relatively large group of buildings that from surface examination suggested functions involving ceremonialism but that were sufficiently aberrant from known types to leave considerable doubt. It appeared after excavation that this group had almost certainly had people resident there at certain times, possibly preparatory to religious rites and ceremonies, possibly for religious training, but that there was little reason to think the structures were houses in the sense of a family residence. Shook and Chowning excavated round buildings that in each case can almost surely be identified as temples. Strömsvik, Chowning, and D. E. Thompson carried on limited excavations at the small ceremonial center next Cenote Itzmal Ch'en in the eastern part of the city. This group was later mapped by Proskouriakoff. Detailed reports of these activities will be found in succeeding sections.

As reported previously, the Department has co-operated, through informal agreement, with the Instituto Nacional de Antropología e Historia of the Mexican Government in carrying out a limited program of repair and consolidation of selected structures at Mayapan. The effort has been to leave on display one example of each of the major types of building at the site. Strömsvik has had charge of this work. During the past season the program of repair was completed with the consolidation of a round temple, of a typical section of the city wall, and of one of the major entrances in the wall. It is believed that future visitors to Mayapan will be able to gain a good idea of the range and character of the architecture there.

During the past season a start was made on the more general studies leading to interpretation of the large amounts of raw data that have been amassed from four seasons of field work. So far these studies have been confined to pottery, work that has rested in the hands of Shook and R. E. Smith. The former devoted the major portion of his time to analyzing the large collections that have accrued from our digging in the main ceremonial center at Mayapan. Because of the wealth of ceramic material recovered during the current season, which was handled by Smith, the latter was able to give less time to such detailed studies. He did, however, prepare a preliminary report, now in press, on the early, pre-Mayapan Period pottery from Mayapan and its vicinity.

As noted earlier in this report, the Department has carried on a program of archaeological reconnaissance in other regions of the Yucatan peninsula than the Mayapan area. During the past season Sanders, working with the Department under a Carnegie Institution fellowship, continued his ceramic survey of the east coast. His work of the previous year had resulted in exploration of the northeastern tip of the peninsula as far south as the ruins of Tulum and including the island of Cozumel (see Year Book No. 53, pp. 292–293). Knowledge gained from this exploration and ceramic testing allowed him to select two important sites, Tulum and Tancah, for intensive work this year in his search for stratigraphic sequences of ceramic remains. Late in the season reconnaissance was extended southward to the Chetumal Bay area, where testing was carried on at the sites of Ichpaatun and Calderitas. With the collections now in hand it is confidently expected we can provide a far sounder basis than previously existed

for the understanding of cultural sequences along the east coast and of the relations of that area with other parts of the peninsula. It is already apparent from a preliminary study of the pottery, not only that many of the East Coast sites are of the same general period of time as Mayapan, a fact that had long been suspected, but that the two areas were unquestionably in contact. It is not unlikely, moreover, that the East Coast remains, because of the sequent stages of culture there, can give us more information on the sources and development of late Maya civilization than the more renowned, but relatively short-lived, capital city of Mayapan.

Archaeological reconnaissance was carried on by Shook in the environs of Merida, along the coast of Campeche, and in the Chiapas highlands. This work was particularly important in calling attention to the wealth of pre-Classic remains, both ceramic and architectural, in one small area of northern Yucatan; in noting on the west coast of the Yucatan peninsula the existence of remains apparently of the Toltec–Chichen Itza type and period, remains that are extremely scarce in Yucatan outside the type site; and in discovering a magnificent stratified deposit of pre-Classic materials in the archaeologically little known upper drainage of the Grijalva River.

Berlin, whose Carnegie Institution fellowship ended during the period covered by this report, devoted his time to the study of, and preparation of a report covering, the archaeological material recovered by him during the two previous field seasons in Tabasco and Campeche. Of special interest was the isolation of a late type of Fine Orange pottery found abundantly along the southeastern shore of the Gulf of Campeche. This same pottery has been encountered in small amounts at Mayapan, thus establishing a chronological and cultural link between that city and the southwest sections of the peninsula. Berlin also visited several small Maya sites where interesting and previously unknown sculptures were recorded.

Beside seeing her forthcoming monograph, *Ceramics for the Archaeologist,* through the press, Shepard has continued her laboratory research in ceramic technology. Several lots of sherds from Mayapan have been examined for evidence of changes in paste composition that might be useful diagnostics for subdividing the period represented, for intrusive sherds that would illuminate foreign contacts, and to evaluate the position of this pottery in the technological history of Yucatan ceramics. Work has also been done on the analysis of Fine Orange pastes preparatory to a study dealing with that important ware. Basic research concerned with the thermal behavior of clay minerals has continued, notably by means of thin sections of polished clay slips which have uniform orientation, facilitating the determination of optical properties. Shepard is also engaged in a review of literature on contemporary pottery making in preparation for a systematic analysis of pottery-making traits with respect to their degree of dependence on environmental conditions, and in order to judge the feasibility of identifying forming techniques of prehistoric pottery by means of the orientation that clay particles are given by the forces applied in building.

Toward the close of the field season Dr. Eduardo Noguera, Director of the Dirección de Monumentos Prehispánicos, Instituto Nacional de Antropología e Historia of the Mexican Government, and Dr. Alberto Ruz L., Head of the Oficina de Monumentos Prehispánicos en Yucatán, visited Mayapan and our Merida laboratories at the invitation of the Department. Dr. Noguera and Dr. Ruz inspected our operations at the ruins, giving particular attention to our work of consolidation of buildings and to our procedures for protecting monuments from deterioration following excavation. At this time we were able to discuss procedures for transferring

guardianship of the archaeological zone of Mayapan to the Mexican Government. This act was accomplished in May 1955, when an official guardian, a native of the village of Telchaquillo, was appointed by the Government.

On July 1, 1955, Earl H. Morris retired, thus terminating thirty-one years of service with the Institution. Morris' first work with the Department was in Middle America, where the Institution was just beginning its large program of excavation and restoration at the ruins of Chichen Itza in Yucatan. It later developed, however, that his true interest lay in the archaeology of the Southwest of the United States, an area in which he had worked for some years prior to joining the staff of this Department. After a few seasons in Yucatan he consequently transferred his operations to the Southwest, where the Institution was willing to undertake a small program, and, with the exception of a single season in Guatemala, his work has continued in the area of his original interest. So successful have been his researches and so outstanding his contributions that in 1953 he was presented the Alfred Vincent Kidder Award of the American Anthropological Association.

Morris' achievements are far too numerous to recount here. Certainly one of his most important contributions to Southwestern archaeology is the result of the part he played in providing specimens from which considerable portions of the dendrochronological master chart for the northern Pueblo area were derived. From his first contact with A. E. Douglass, he was convinced of the soundness of the Douglass method, and his imagination was fired by the high promise it offered not only for dating specific ruins, but also for delimiting the several stages in Basket Maker–Pueblo culture, the sequence of which had previously been established through stratigraphy. All that seemed necessary was to obtain enough samples of wood of usable species. Through the years, the hundreds of sections that were turned in to Douglass and his associates provided several basic portions of the San Juan chronology and aided in bridging what had been floating series. It may safely be said that without the material which Morris supplied, this chronology would not yet have been carried back through the early centuries of the Christian Era to its now nether limit of 59 B.C.

On July 1, 1955, Margaret W. Harrison resigned as Editor of the Department of Archaeology, ending an association of twenty-one years with the Institution.

As a tribute of recognition of his outstanding achievement in archaeology, the Government of Guatemala has conferred on Alfred Vincent Kidder, past Chairman of the Division of Historical Research, the decoration of the Order of the Quetzal, in the grade of Knight Commander.

Mayapan, Yucatan

Karl Ruppert and A. L. Smith

The square-by-square surface examination of the building remains at Mayapan having been completed during the 1954 field season (see Year Book No. 53, p. 267), the 1955 season, with the exception of two weeks, was spent in excavation at the site. One week not consumed in excavations was used in checking a survey of house types lying within a distance of about 12 km from Mayapan. This survey was undertaken by three laborers, residents of Telchaquillo. The other week was spent at the ruins of Chacchob. At the end of the season A. L. Smith and Strömsvik made a one-day trip to Tulum, a walled site that has many architectural and ceramic similarities to Mayapan.

During the season Ruppert and A. L. Smith excavated 26 structures at Mayapan. The purpose of this work was twofold: to try to get, through thorough excavations, sealed samples of pottery, and to determine the possible functions of the structures investigated. During the three previous years, Ruppert and Smith had devoted several weeks of each field season to

excavations in various structures throughout the site, with emphasis on the average dwelling. This year some of the more elaborate dwellings were chosen, as well as structures with unusual ground plans. In the selection of structures for excavation, their distribution was taken into consideration, so as to have examples from all parts of the site. Several whole groups were also excavated. These consisted of elaborate dwellings with beam-and-mortar roofs, thatch-roofed dwellings, and simple low platforms with no traces of superstructures, arranged, in each case, around a court with an altar or altar shrine in the center.

In most cases the more elaborate variety of building investigated had two or more columns, built of stone drums, dividing the opening in the front wall into three or more entrances; the masonry was better than average, more Puuc-type stones were used, and roofs were of beam and mortar. In one instance, Structure J-71b, there were masonry piers instead of round columns. In another very elaborate dwelling, Structure Q-244b, the upper part of the façade had so fallen that it showed there had been five courses of stones measuring about 60 cm from the supporting beam to the top. There was also one jamb still standing to a height of 1.70 m, which, plus about 20 cm for the beam supporting the upper façade, gave a total height of 2.50 m for the building. The presence of quantities of charcoal and the remains of burned beams on the floors of some structures with beam-and-mortar roofs indicated that they had been burned.

Types of structure other than the typical dwelling were altars, altar shrines, one-room constructions with two columns in the opening in the front wall and two columns inside the room, and one-room structures with or without columns in the front opening. Buildings of the last type may have had a bench around three sides with a recess in the center of that part of the bench extending along the back wall, forming a small shrine or altar (Structures P-28b and R-171b). In one instance, Structure Y-8b, such a structure had a passageway through the bench along the back wall leading into a shrine room which projected behind the building. Two constructions, Structures R-126a and Q-37a, each of a single room with two columns inside the room, had benches on three sides with an inset in the center of the bench along the back wall. Structure R-91, also a one-room building with two interior columns, had no bench but had a raised area in the center of the back wall. Four stucco human feet on the floor directly in front of the altar and stucco remains on the altar indicated that it supported two seated figures. Structure P-23c differed in that it had only one interior column, placed in the northern half of the room. There were benches along the back wall and north side, the former having a central recess. A doorway led out of the south end of the room. An interesting feature of this structure was an outside platform, abutting the north end, with postholes in the outer corners. The presence of ash and three metates strongly indicates that this was a kitchen. Another type of structure excavated faced in two directions, the opening on each side being divided into three doorways by two columns (Structures J-71a and S-133b).

As far as function goes, there is no doubt that the buildings which so closely follow Landa's description of house constructions in Yucatan (Tozzer, 1941) were used as family dwellings. These are structures with a front room, open along the front, with benches and with one or more passageways leading into a back room which may or may not have had benches or an exterior doorway. There is also no doubt about the functions of altar platforms or altar shrines in the court of a house group. These were surely family shrines. Sometimes altars and shrines occur inside or are a part of a dwelling. Platforms with no signs of superstructures are a problem, as they may have supported wooden structures which could have served many pur-

poses, such as kitchens, temporary shelter for guests, etc. The one-room structures with benches and altars and sometimes with interior columns could have been used as dwellings of priests and served a religious purpose as well. They certainly would not lend themselves to a family group. Structure R-91, a single-room building with two interior columns, no benches, and an altar supporting two stucco figures, must have had a purely religious function.

Several of the structures excavated had earlier constructions under them, and sealed samples of pottery were recovered. All had sherds from the Mayapan Period.

In the course of digging, a good many burials were encountered. These occurred in simple cists and in well-made vaults, and bore out evidence from former years that there was no definite rule about burying the dead, both method and location varying greatly. Two particularly interesting stone-lined burial vaults were found under benches in the east room of Structure S-133b. These vaults could be entered by means of low, narrow passages through the wall of the room to the west.

Grave furniture is scarce at Mayapan, but mention should be made of copper rings and a pair of copper tweezers among the objects recovered. Of interest was a complete pottery doll with articulated arms and legs.

During the first part of April, Ruppert and Smith spent five days at the ruins of Chacchob, a walled site visited by Pollock and Strömsvik in 1952 (see Year Book No. 51, pp. 259–263, and C.I.W. Current Report 6). The purpose of the trip was to investigate the house types at the ruins and to get pottery samples. According to Pollock and Strömsvik, all the structures they saw seemed to be of the Puuc period. The house structures investigated by Ruppert and Smith proved to be of this period, containing only Puuc types of pottery, with the exception of a small single-room building, possibly a shrine. This latter, which was partly built of re-used or discarded Puuc-type stones, contained Mayapan pottery, showing that the site was occupied in Mayapan times.

Throughout the season two or three men were employed in searching the environs of Mayapan within a radius of about 12 km for house structures, the purpose being to find how far the types found at Mayapan extended outside the site. They visited 111 sites, consisting in most cases of a few structures associated with a cenote. Rough plans were made of structures, and samples of pottery were recovered when possible. Near the end of the season Ruppert and Smith spent about a week checking the most likely sites, and found that at only two were there houses of recognizable Mayapan types as far as 12 km away. These were the sites of Itzin Can and Xtubi Ch'en, both to the west. In all other directions Mayapan house types disappear within 3 or 4 km.

Excavations in a Large Residence at Mayapan

Tatiana Proskouriakoff and Charles R. Temple

Preliminary mapping and excavation in Group R-85 to R-90 in 1954 (Year Book No. 53, pp. 270–271) established that it was an unusually elaborate residence and suggested three points of interest on which we based our plans for the present investigation. Primarily, we were interested in the sequence of major building operations and in the ceramic types accompanying each stage. This, we hoped, would give us some idea of the length of occupation and of possible changes in the function of the group, in addition to providing sealed deposits for ceramic study. Secondly, we looked for tombs, expecting to find in them ceremonial and luxury objects appropriate to a rich household. Finally, we planned to excavate what we surmised to be a kitchen, since none had been surely identified elsewhere at Mayapan.

We found that the building site of the quadrangle was unoccupied during the early period represented by so-called "Puuc"

Slate and coarsely striated pottery wares, although a few sherds of this period turned up in soil overlying bedrock. The later black-on-cream ware associated with the earliest constructions of the main ceremonial group was also virtually absent here, and we concluded that a considerable period of time had elapsed between the foundation of the ceremonial center and the building of this residence. Extensive rebuilding and numerous minor alterations, however, led us to believe that the group was occupied at least for the span of several generations before its final abandonment, which in all probability took place when Mayapan was violently destroyed in the middle of the fifteenth century.

The original plan included a broad terrace supporting two building platforms joined at a right angle, and a vaulted underpass near the juncture. We are not sure which way the group faced at this stage, but soon afterward a monumental stairway with a central shrine was built against the east terrace wall. Later, the main terrace was extended forward and to the north, the building platforms were lengthened and broadened, and their superstructures were several times rebuilt before, with the addition of new structures, the quadrangle assumed its final shape. Although too little of the earlier plans was recovered to ascertain the original function of the buildings, the general similarity of early and late arrangements and the continued use of an early shrine gives the impression that the group was planned from the beginning as a residence. At the end of its occupation, at least two of the principal buildings were destroyed by fire, evidently very soon after their inhabitants left, for a number of abandoned pottery vessels were found broken but still in place under the debris of burned roofs, although all articles of value had been removed from graves and caches.

The looting of the caches disappointed our hopes of finding luxury items intact. Of the prized materials, only a few jade and shell beads were recovered, several copper bells, and some minute fragments of thin gold. In Structure R-86, however, we came upon a plundered tomb that had been refilled to the brim with ceremonial objects, evidently collected and either purposely cached or simply dumped as too cumbersome to carry away. Among other things, the tomb contained several small sculptures, a huge number of fragments from figure censers with some well-preserved heads of deities, and various restorable pottery vessels of distinctive late types.

This cache or dump explains the lack of ceremonial material in the central rear rooms of house structures R-86 and R-87. These rooms contain altars and probably served as domestic shrines, although the only ritual object we found in place was a small sculptured turtle in Structure R-87. In both rooms there were large storage jars thickly coated with plaster, and in one corner of the room in Structure R-87 there was a small drain formed by a jar neck set in the floor. These features, implying the ceremonial use of water, were quite unexpected. One wonders if some form of ritual bathing was practiced here, especially since we have found no other facilities for this custom at Mayapan, such, for example, as the sweat houses of Chichen Itza.

The excavation of Structure R-86a proved to be particularly interesting because this structure, which was a kitchen, as we previously guessed, was abandoned with most of its pottery equipment intact and gives us a good idea of the range of utensils used in cooking. The kitchen is actually an integral part of Structure R-86, but it also served Structure R-87, communicating with both houses by doorways and also by small apertures in the end walls of their front galleries. The main walls and columns of the kitchen date back to a time before either house was built, and it is not clear whether it had also served as a kitchen for earlier houses. In its final form, it was a room roughly 5 by 6 m, with a large L-shaped bench on its west side, and a smaller bench on the east, partly

blocking what was originally a wide entrance with two columns that now faces the end wall of Structure R-87 across a narrow corridor. Another wide opening, leading to an open colonnaded gallery on the south, is blocked by a low wall against which is placed a hearth. This rests on the finished floor and consists of three flat stones, originally partly surrounded by a semicircle of upright stones, of which only two remained in place. There may have been a similar hearth on the east bench. Between the two hearths, in the corner of the room, stood a large water jar and several other vessels. More vessels were grouped on the two benches, and fragments of others were scattered on the floor. There was no dirt or other debris under the burned beams and plaster of the fallen roof to suggest that the room stood abandoned for any length of time. The pottery is all of very late types, some of which have slightly convex rims, foreshadowing the peculiar form of the "parenthesis" rim of the colonial period.

Surprisingly few stone artifacts were found in the kitchen. Smaller articles may have been carried away, but the absence of manos and metates shows that corn was ground and prepared outside, probably in the open colonnaded gallery back of the kitchen. A number of metates, manos, and other stone utensils were scattered on the surface in the gallery, in the debris at the foot of the outer terraces, and near a stairway on the west that leads to the kitchen entrance. A few meters to the north of this stairway, where a trench had been opened to expose the base of a terrace, we found a number of large, very roughly chipped flint tools, some of which resemble crude axes.

In search of early pottery levels, we dug another trench at the outer opening of the vaulted passageway just east of the kitchen. Here we exposed a deep stratum of ash filled with animal bones and fragments of pottery, apparently a kitchen midden that had been leveled to build the latest minor additions to the outer terraces. The pottery collection from this midden, although it includes a few simple figurines, contains almost no censer sherds and represents, almost exclusively, utilitarian wares with an unusually high proportion of lightly striated unslipped gray sherds. The animal and bird bones recovered have been brought to the United States for identification in the hope that they will furnish significant data on the dietary habits of the Maya. Since the ash layer covers early construction, and later additions are built upon it, the collections should be well placed in time when all the implications of the stratigraphy are worked out.

Excavation of a Residential-Type Group in Mayapan

J. Eric S. Thompson and Donald E. Thompson

The group formed by Structures Q-169 to Q-173 was excavated as a part of a program initiated last year (Year Book No. 53, pp. 279–81) to investigate supposed residences of the nobility. It is situated immediately southwest of the Castillo, closer to the hub of the ceremonial center than one would expect to find a residential group, and is composed of six buildings. Three of these are built around a small court, open to the east, in the center of which stands Structure Q-170, a small shrine.

Structure Q-169, the most important building, stands on a fairly high platform occupying the south side of the court. Such of the building as was exposed before excavation indicated that it was a residence of persons of consequence. It comprises a long room with four benches and an open front with four columns, two narrow rear rooms, and a west room with two benches, exterior doorways, and access to the front and west rear rooms. Masonry throughout the building is unusually fine; much of the stone is re-used Puuc type. Drums of columns had been cut with more care than was customary at Mayapan; indeed, several fall little short of being truly cylindrical. Thick layers of mortar above the floor were conclusive evidence that the ceiling

had been of beam-and-mortar type. A small altar (looted before the collapse of the roof) set against the back wall of the larger rear room and along the central axis of the building is indicative of a private shrine, but no incense burners were on or near it, or in any other part of the building, a situation paralleling that encountered in the large residence (Structure Q-208) excavated last year.

Unfortunately, the floors were entirely free of artifacts which might have helped to clarify the function of the building. Certainly no kitchen was there, and there was no evidence that pottery vessels for eating or even to hold drinking water were kept in the building.

Below the front room and immediately in front of the central doorway to the rear room and altar is a large tomb, the floor of which is below plaza level. The roof is in the form of a crudely corbeled vault, the top of which had apparently been closed with wooden beams or planks in place of the usual capstones. In the tomb were a partly disturbed supine burial, twelve small and crude tripod bowls of Mayapan Redware, a handled brazier, and one copper bell. The last was partly hidden under a shin bone. As copper bells are not believed to have been used singly, and in view of the disturbed condition of the burial, it is probable that looters entered the tomb, but overlooked one bell, before the roof of the building collapsed.

The small building in the center of the court yielded no fragments of incense burners or other evidence of having functioned as a religious building, although its size and location suggested that it had been a shrine.

Structure Q-171, on the north side of the court, was a thatched building. There is a long room with benches and open front, narrow rear rooms, and an exterior bench at the east end. It obviously was residential, but it is difficult to suggest the relation between its residents and the occupants of Structure Q-169.

Structure Q-172, a beam-and-mortar-roofed building occupying the west side of the court, proved to be of considerable interest because one of its two rooms was clearly for ceremonial use, whereas the other appears to have been residential. Room A contained an altar set against the back wall and benches against the flanking walls. Along the top of the altar, at the back, were the badly smashed remains of about a dozen incense burners. Below the daislike step in front of the altar was an ossuary holding the jumbled remains of five persons and a pair of copper tweezers. Inside the altar was a well-made pottery jar, with a tripod bowl set as a lid in its mouth and sealed in position with mortar. The jar was two-thirds filled with a very fine ash mixed with small fragments of bone. This is the first cremation in a sealed jar found at Mayapan.

Bishop Landa mentions the depositing of cremated remains in large casks over which temples were built, and he also writes of the offertory rites to the ancestral remains which, together with their idols, were kept in the oratories of nobles' houses. Although Landa describes more elaborate rites than the sealed cremation of Structure Q-172 suggests, the placement of this carefully sealed crematory jar beneath the altar does give the impression that a cult of ancestor worship, not unlike that described by Landa, had developed at Mayapan and had its focus in the private family oratory.

All in all, it is highly probable that this Room A of Structure Q-172 served as the private chapel of the residents of the group or, perhaps, only of the family resident in Structure Q-169. In contrast, Room B, from which there was no direct access to Room A, shows no evidence of having served religious ends. It contains two large and handsome benches, one against the west wall, the other against the north wall, and its main doorway does not give on the court, but is on the south side (a doorway giving on the court had been blocked). Clearing of the room revealed no clues to its function. As we have no reason to suppose that professional priests

were employed to minister in family oratories, it is highly unlikely that this room was a priest's residence. There is, however, information that in some parts of the Maya area, including Yucatan, men retired into seclusion for the periods of fasting and continence which preceded many, probably all, ceremonies, both public and private. Indeed, segregation of male participants before and during a religious rite is still practiced in Yucatan. It is, accordingly, possible that this room with its benches adjacent to the oratory was reserved for occupation by the men of the group before some important ceremony, of the family if not of the whole community. That the main doorway of this room is close to the side steps to Structure Q-169 may be significant.

Structure Q-173 is a small, irregular building with thatched roof which is off the court and faces south, just west of Q-172. Excavation supplied no evidence as to its function beyond the fact that benches divided by a medial wall suggested a residence. Plausibly it was the home of menials who served the occupants of Structure Q-169.

In the angle between Structures Q-172 and Q-173 was a most unusual construction. This was a quadrant-shaped room which presumably served for storage, since access to it was through the roof or through an opening in a now fallen part of the wall above floor level. The floor of the room was largely bedrock, with an irregularly shaped crevice in the middle. The position of the room (between the back walls of two structures) and its appearance and construction suggest that it was used for water storage, but the walls of the crevice are not now waterproof. The absence of broken storage jars and the presence, in a pocket of the crevice, of the pieces of a shallow tripod bowl with effigy feet hardly support the suggested use as a cistern. Alternatively, the room may have served as a granary.

The western part of the front room and the west rear room of Structure Q-208, not excavated last year, were cleared this season in order to complete the tally of imperishable objects that looters may have rejected or overlooked before they set fire to the building. Ash and charcoal in great abundance in the west rear room showed that here too the ceiling had been set afire. The only artifacts, apart from a miscellaneous lot of sherds, some from the roof mortar, were one unretouched obsidian blade from a core, and three matching human effigy feet from a bowl of Mayapan Redware. As no other pieces of the bowl were found, it seems probable that these feet, to one of which a section of base still adhered, had some secondary use. Could they have been a child's playthings?

Excavations at Mayapan

Donald E. Thompson

The major part of the season was spent in excavating for architectural features at the Itzmal Ch'en ceremonial group, reported by Chowning, and in a thorough examination of the latest period of a residential group reported by J. E. S. Thompson and the writer. Toward the end of the season, Structure Q-165, herein discussed, was investigated because of its proximity to both a colonnaded hall and a residence, Structure Q-168, excavated by Chowning. It was hoped to discover, if possible, the function of the building and its affiliations.

Structure Q-165 was composed of two rooms connected by a doorway. The larger and main room faced a small court on which the residence, Q-168, also opened. The colonnaded hall, in line with Q-165, faced in the opposite direction, though access to it may have been possible through a space between the end walls of the two buildings. The smaller room faced the opposite way, the same direction as the hall; but it also opened on Structures Q-166 and -167, small outbuildings associated with the residence. Since the residence formed a broken T with the end of Structure Q-165, this back door also gave access to one end of the residence.

The main room of Structure Q-165, facing the small court, was of rectangular plan, with two L-shaped benches meeting at the rear center at an altar. The roof, undoubtedly beam and mortar, to judge by the depth of debris and the high plaster content, was supported in the center by four columns, two in the doorway and two, more widely spaced, on the longitudinal axis. The masonry was fairly good, in contrast to that of the other room.

In front of the altar was an ossuary cist containing five burials, two figurines, and a pottery jar. Despite a relative lack of incensario sherds, the altar and ossuary cist argue for this room's being considered a shrine, which, because of the direction it faced, probably served the residence Q-168. Since there was not room in the cist for five complete bodies at once, and since some of the bones were articulated and others were disturbed, it seems likely that the cist served as a family vault and was in some way connected with ancestor worship, the bodies being placed there at death, so that there was time between burials for decomposition to take place.

The adjacent room opening to the rear of the structure was built of very inferior masonry. The floors were almost entirely missing; just enough remained to establish a top floor, level with that of the main room, and a lower one, in places just above bedrock. To judge from the ashy soil, type of refuse, and quantity and type of artifacts, the room served as a kitchen or workshop during at least one period of its existence. Just above bedrock were found three burials which apparently are to be associated with the upper floor.

In the center of the room a narrow natural opening, which had been artificially widened, led down to a small natural cave. The opening had been plastered around the mouth and covered with several slabs of stone. Within the cave were three burials and a bowl, broken but with large pieces in position, containing charred human and animal bone and ash, presumably representing a cremation. A potlid from very near by may have covered it, though the fit was poor. Grave goods were almost completely lacking in all burials.

Structure Q-165 seems to have served the dual purpose of shrine and kitchen. The shrine appears to be associated with the residence Q-168. The kitchen, facing the outbuilding at one end of Q-168, could have served as the kitchen for this house or could possibly have been used for the ritual preparation of food for the colonnaded hall. Chowning suggests that Structures Q-166 and Q-167 may have been kitchens. If this is so, then the probability of association with the hall is increased. The doorway between the kitchen of Q-165 and the shrine room suggests religious use of the former, possibly for the serving of food to persons secluded in the shrine during a period of special diet and continence. It is possible, then, that the group as a whole answered the demands of the colonnaded hall, the shrine serving the residence and the attached kitchen serving the hall and the members of the household secluded in the shrine. If Q-166 and Q-167 were for culinary use, this would presumably be to prepare the daily food of the occupants of Q-168.

Excavations at Mayapan

Ann Chowning

Late in the season Chowning excavated three connected house mounds in the Main Group, Structures Q-166, -167, and -168. They seem to belong to an assemblage which also contains a colonnaded hall, Q-164, and Structure Q-165, excavated by D. E. Thompson. The three structures in question stand on a single L-shaped platform, with the principal house, Q-168, forming the shank of the L and facing southeast. Like Structure Q-165, which is parallel to the short arm of the L and almost touches it, Q-168 faces a small built-up area, supported by a terrace wall which runs from the east corner of the building platform and seems to contain a staircase leading to the group. The house platform

is interrupted in front of Q-168 by what may be the entrance to the house. Two lines of large stones set on end, the front line lower than the rear, run across the front of the house. The side and back walls are low, and the lack of surface debris indicates that the upper part of the house was composed of perishable materials. There are three benches, one of them L-shaped, in the front room, medial walls behind each, passageways between them, and two benches in the back room. There is no sign of an altar, nor any indication that ceremonial activity was carried on in the building, though fragments of three human figurines and of effigy incensarios were found in the fill of the benches. One of the rear benches completely fills the space between the medial and back walls, but the other is set against the back wall, and next to it is a passageway to an end room, which is cut off by a wall running the length of the L-shaped front bench. This room contains benches in two corners, and another construction partly within the room but extending beyond the back wall; presumably it is an exterior bench. A doorway in the side wall leads to Structure Q-167. Excavation within the passageways and benches of Q-168 revealed no burial crypts, but fragments of human bones were scattered in the fill in front of one of the front benches, and the skeleton of a child, accompanied by bone and shell ornaments, bone awls, and an obsidian arrowhead, was found under a bench in the end room. A broken metate, several manos, including part of one of which the remainder was found in Structure Q-165, and heavy concentrations of coarse household ware indicate that this was a simple dwelling, like many others in Mayapan, in which domestic activities were performed.

The plan of Structure Q-167 is not nearly so clear, and it is difficult to say whether, in fact, one structure or more than one is represented. It fills the angle of the L, and contains an L-shaped bench behind which is a wall that continues as the terrace wall of the short leg of the platform. The orientation of the bench and the wall indicates that this structure faced southwest, away from the plaza, and a break in a low wall in front of the bench may be the doorway. Another narrow bench connects this one with a larger bench which was built against the side wall of Structure Q-168, and in front of the connecting bench is a square bench which is independent of any wall. The floors in this part of the structure are considerably higher than those in front of the L-shaped bench. Attempts to find a wall around the part of the structure adjacent to Q-168 failed. The fill of this structure is true midden debris, full of ash, animal bones, and the sherds of household pottery, and it seems likely that a kitchen, possibly that of Q-168, is represented by at least a part of the construction. Similar midden debris is piled against all the terrace walls in this group.

Structure Q-166 occupies the end of the L, and is separated by a narrow strip of plaza floor and bedrock from Q-165. It has a clear back wall, a single bench with a medial wall behind it, and a narrow passageway and side exit behind the bench. It again faces the plaza, and the unwalled platform seems to have functioned as the front part of the structure. It stands on a higher level than the adjacent parts of Q-167, and there is no sign of a doorway between the two. The use of Q-166 is conjectural, but the debris within and around it is like that of Q-167, and it probably was part of the same domestic assemblage. A pair of terrace walls runs behind both these structures. A few fragments of effigy incensarios and a figurine head are the only indications of religious life, and both are often found in simple households. The proximity of the three structures to Q-165 indicates that they are connected with it, and perhaps with the colonnaded hall Q-164, but the nature of the constructions and the artifacts within them makes it evident that the role of those who lived and worked here was a subsidiary one, possibly that of servants to the occupants of the more important structures of the group.

Excavations in Mayapan

H. E. D. Pollock

In 1954 a series of test excavations were carried out by Pollock at the northern terminus of the principal sacbe, or artificial road, at Mayapan (see Year Book No. 53, p. 279). This work was done with the intention of determining the time of construction of the sacbe in relation to the architectural assemblage at its northern end and, so far as possible, in relation to the span of occupation of the city. Somewhat surprisingly, it developed that the road was a relatively late construction.

During the field season covered by this report, similar, but slightly more extensive, operations were instituted at the southern end of the sacbe where it terminates at the somewhat smaller assemblage of buildings known as Group Z-50. The time of construction of the road was checked, as had been done at the northern end, and in addition Group Z-50 was mapped and limited excavations were made that led to some, but by no means complete, understanding of the growth and nature of the complex.

Group Z-50 is a raised courtyard enclosed by buildings on the east, south, and west, and entered from the north, where a stairway rises from the surface of the sacbe to court level. Near the center of the court are several low platforms suggestive of altars, and a stone of the sort that is thought to have been used for human sacrifice. A simple geometric design runs around the stone. A short distance west of the sacbe a subsidiary stairway rises from ground level to the northwest corner of the courtyard, and two other stairways, also rising from ground level, are on the east side of the group. Between them, built into the main platform, is a small room entered from ground level. The ceiling of this room, which had been roofed by beam-and-mortar construction, must have been about on the level of the surface of the main platform, which here forms the eastern terrace of Structure Z-50a.

Structure Z-50a, the eastern building, consists of two rooms separated by a medial wall with a centrally placed doorway. Each room is entered by a two-column doorway, the one facing east, the other west on the courtyard, and by doorways at each end of each room. Two benches are built along the medial wall in the west room; there is one in the east room. To judge from the depth and character of debris, the roof was of perishable materials, presumably thatch, although the stone walls must have risen to considerable height. This is a type of structure that is relatively rare at Mayapan. It is known to occur in groups of buildings that almost surely were domiciliary. The extraordinarily open plan of Structure Z-50a with entrance from all sides, however, does not suggest the privacy one expects in the typical family residence. At present we are uncertain of the function of this type of structure. It is entirely possible it was for dwelling purposes although not the residence of a family.

Structure Z-50b, the southern building, faces north on the court, where it is entered through a wide two-column doorway. The large front room has a single bench in its southwest corner and a centrally placed doorway in its rear wall that leads to a narrow chamber, without other entrance, occupying the southwest corner of the building. Against the back wall of this room and the back wall of the building, just opposite the doorway, is what we take to be an altar rather than a bench, because of its central location and narrow proportions. From the fill of this altar we removed a little tripod cup of a type commonly found in caches, and a jade bead that had undoubtedly once been inside the now broken cup. East of the front and rear rooms, running around the southeast corner of the building, is an L-shaped chamber entered by single-column doorways on the south and east and by a narrower doorway on the north. This room does not communicate directly with either of the other rooms. A large bench, which

blocks the southern half of the eastern doorway and part of the southern doorway, fills the center of the room from wall to wall. Against the east face of this bench, and outside the doorway, a smaller bench, added secondarily, rests on what was a secondary widening of the terrace of the building at that end. The latter bench is thus in the open, but it is entirely possible that this whole area had been covered by thatch, although the rest of the structure had carried a beam-and-mortar roof. Although Structure Z-50b is hardly typical of Mayapan dwellings, the bench and terrace arrangement at the east, which suggests kitchen appointments, leads one to suspect that this structure may have been used, at least in part, for domestic purposes. Debris of the nature of a kitchen midden was found in the corner between the south end of Structure Z-50a and the east end of Z-50b. This refuse may have come from either building.

Structure Z-50c, a long single-room building that lies along the west side of the group, is approached through a wide four-column entrance facing on the court. Two benches and a centrally placed altar, in front of which were fragments of incense burners, run almost the entire length of the rear wall, ending just short of the north end of the room in order to allow passage through a doorway in the rear wall. This doorway and one in the north wall let onto a narrow terrace that runs along the back of the building and across the north end. At the south end of the room a doorway opens to a small courtyard or terrace between the ends of Structures Z-50b and Z-50c. The character of the debris in the room left no doubt that the building had carried a beam-and-mortar roof. At the north end the charcoal remains of a roof beam and the fire-blackened floor indicated that this part of the roof had burned. Oddly enough, similar signs of burning were not found at the middle of the room, the only other area cleared to floor surface. Structure Z-50c, in plan and interior arrangement, is rather similar to the colonnaded halls found in the main ceremonial center at Mayapan. There is reason to believe that such structures, although primarily ceremonial in nature, were lived in by certain groups at certain times. Structure Z-50c may well have seen similar use.

The previously mentioned area that lies south of Structure Z-50c and west of Z-50b carries the remains of the usual plaster flooring. In this floor, toward the eastern side of the area, is an opening into a roughly built chamber in the fill of the terrace that reaches bedrock and resembles a chultun or cistern. The chamber shows no indication, however, of ever having been watertight; indeed, the open fill that forms its sides and the creviced bedrock of the floor give quite the opposite impression. The relatively meager amount of pottery, stone implements, and bones that came from the debris in the chamber also seems to rule out its use for the disposal of refuse. If by any chance the Maya provided toilet facilities within their buildings, a practice that does not seem very likely, this opening might have served such purposes. No other construction was noted in this area. Although the terrace was only partly cleared, the debris was not deep and any walls of stone would presumably have been observed. If the area was roofed or was walled at the south and west, such construction must have been of a perishable nature.

Our excavations in this group were limited, being designed primarily to date the sacbe and to obtain a plan of the architectural assemblage in its final stage. There nevertheless emerged some indications of building sequence and the growth of the complex. To judge by the joints between the plinths or building platforms supporting the three structures, Structure Z-50b was constructed before Z-50a and Z-50c. Evidence involving the growth of the main platform of the group indicates that Z-50c was the last built. We also ascertained that the sacbe had once extended 7–8 m farther south to an old terrace wall buried by the

subsequent northward extension of the main platform. There were the barest traces of what may have been a stairway at the earlier terminus of the sacbe. Lastly, there was some indication that the main platform had been extended westward to enable the building of Structure Z-50c.

The pottery from the fill of the sacbe checks the conclusion from our work of the previous season, namely, that the road is a late construction with reference to the occupation of the city. Indeed, the pottery from all our digging at this group suggests a late period. There seems to be one difference between the situation at the southern end of the road and that at the north. We know that some construction, viz., the northward extension of the main platform, and possibly a western extension, was carried on at Group Z-50 after the completion of the sacbe. Indications—and it should be stressed they were no more than indications—at the other end of the road were that the sacbe may have been built when the architectural complex there had reached its final form.

The function of Group Z-50 in the life of the city is not so clearly marked as in the case of many other structures. It has been noted in preceding paragraphs that none of the buildings in the group are typically residential, in the sense of the family domicile. The sacrificial stone in the courtyard—if our identification of this form of monument is correct—is not the sort of object one might expect to find associated with the family dwelling. It should be remembered that Group Z-50 is connected by a relatively imposing roadway with a large assemblage of buildings that probably was a residence of the nobility or aristocracy. One wonders if the road would lead from this residence merely to another group of dwellings. In spite of these indications that Group Z-50 was not a residence in the sense of the primary living quarters of a family or extended family group, the fact is that the nature of the pottery, and to a lesser extent the artifacts of other materials, that was recovered is just about what one might expect from habitations. Taking the evidence in hand, and it leaves much to be desired, it is probably best to think of this group of buildings at the southern end of the sacbe as being essentially ceremonial in nature but involving rituals that required residence during certain periods. One suspects, moreover, because of its connection with the imposing structures at the northern end of the road, that the use of Group Z-50 may have been restricted to the occupants of the other group.

Excavations in the Itzmal Ch'en Ceremonial Group at Mayapan

Ann Chowning

D. E. Thompson and Chowning spent much of the season investigating the small ceremonial group in Square H, next to Cenote Itzmal Ch'en. The group, which is located near the city wall in the thinly populated eastern part of Mayapan, consists of four large structures, H-14, -15, -16, and -17, one on each side of a rectangular plaza, and a fifth structure, H-18, roughly in the middle of the plaza; a sixth one, H-12, lies outside the plaza proper, near the edge of the cenote. Four smaller associated constructions, H-13, -16a, -17a, and -18a, presumably functioned as shrines. All these were excavated sufficiently to make their ground plans clear; only Structure H-18 and the shrines were investigated more thoroughly. Later, all the structures were included in a map of the group prepared by Proskouriakoff. Trenches were also run from H-18 to H-15, H-16, and H-17 in an attempt to determine the temporal relations of the buildings and to obtain stratified pottery samples.

The plaza of the group is on a natural rise in the limestone, which has been leveled in places by the addition of an artificial fill of stones. Supporting terrace walls run around the edge of the plaza, which is approached by a staircase on the west side. In most parts of the plaza only two plaster floors are visible, though next

to buildings the number sometimes rises to five. No floor was complete enough to make it possible to establish the exact chronological relations of different parts of the group.

The main structure of the group, H-17, stands on the north side, and, like all the other structures, faces the plaza. The substructure is a pyramid with two terraces and a staircase which is inset at the top; the pyramid is surmounted by a small temple. The temple, resting on a plinth, has a two-column doorway facing south, two interior columns, and L-shaped benches. At the rear of the building is an altar probably supported by four crouching human Atlantean figures made of stone covered with painted stucco. The two central figures were still supporting a large slab, but the exact form of the altar top is uncertain. A crudely carved jade head was found in the floor under the altar, and incensario sherds, three stone turtles, and a stone jaguar lay near by. One of the interior columns was originally painted in bands of red, yellow, black, and blue-green, but this decoration was later covered by a layer of plain white plaster. An unknown excavator had dug a trench through the rear wall next to the altar. Incomplete walls and a column adjoining the west wall of the temple indicate that another structure once stood there. The present pyramid represents at least the third remodeling of the substructure.

At the base of the stairway is a complex shrine, H-17a. On one side of it is a low platform or bench, in front of which stand the sandaled feet of two large stucco figures, and, between them, a large stone serpent head. Two similar heads lay a short distance away, and a stone of the type thought to have been used for human sacrifice is set in front of the figures. Another platform, of more irregular shape, extends to the west of the first one, and between it and the staircase were several pieces of sculpture, including a round "altar," a square one, and three carvings of serpents; any or all of them may have fallen from above. The exact plan of this part of the shrine is not clear. A stone "diving god" lay on the surface.

Directly south of Structure H-17 is a round building, H-18, which stands on a square platform with a balustraded staircase on each side. The temple has four doorways, oriented, like the stairs, to the cardinal directions. This fact is particularly interesting because this is the only round structure at Mayapan to have four doorways, and Landa reports a legend that such a building was constructed there. In the middle of the single room is a round pier, 1 m in diameter, built around an earlier central column and resting on a wide circular plinth. In the pier are four niches facing the doorways of the room, and in the west niche, which seems to have been made to accommodate it, rested a well-made round stone altar, under which one jade bead was found. It is impossible to say how much taller the pier, now almost 1 m high, formerly stood; presumably the central column, and conceivably the pier, helped support a beam-and-mortar roof. A stone monkey with tenons on its back lay in front of the south niche, and a turtle with badly weathered glyphs on its back was found beside the substructure. There were remarkably few incensario sherds inside the temple, though the floor showed signs of burning.

The present substructure encloses an earlier one which stood to the same height and also had four staircases, all but one of which were largely destroyed before rebuilding. No traces remained of any earlier superstructure. On the north side of the substructure a crypt was built, using a balustrade and wall of the earlier substructure, the wall of the later substructure, and a specially built end wall for its four sides. In this crypt, in a space roughly 1 m long, 50 cm wide, and 1 m deep, were jammed the well-articulated skeletons of fourteen adults. There were no grave goods except a large conch shell at the bottom of the crypt. The bodies were of both sexes, showed a considerable age range,

and obviously were put in at different times. The skulls of two were missing. The unceremonious manner of burial and the proximity of the crypt to the sacrificial stone in front of Structure H-17 suggest that the skeletons represent the victims of the rites thought to have been performed there.

Southwest of Structure H-18 is a small construction designated as H-18a. It is built directly on the plaza floor and has three parts. One is a low platform in front of which are the remains of two pairs of stone-and-stucco feet. The scattered parts of the rest of one of the figures, including both hands holding flattened balls, lay in front of the feet; the other figure seems to have been destroyed earlier. Just west of this one is a much cruder platform or bench. To the south of these constructions, and hiding one of the pairs of feet, is a low-walled, three-sided enclosure, the open end to the west, surrounding the upper half of a large stucco figure which lay on the plaza floor. The rest of the 1.25-m figure was unprotected, and if the walls ever bore a superstructure, it was of perishable materials. The figure wears a garment resembling feathers, and elaborate wrist and ankle ornaments. Its arms and legs are spread so that the elbows and knees form right angles, and on these joints are death's heads, like those depicted on the joints of the Aztec "earth monster." The hands and head of the figure are missing, but scattered plumes may represent part of a headdress. This figure lies over a similar smaller one which was carved in high relief on a single block of stone almost 1 m long. The stone figure also has skulls on its joints, and serpent heads of classic Maya type were carved in low relief between the arms and legs. Large round holes which pierce the stone represent the eyes and presumably had a functional use; they were the only part of the stone visible under the later stucco covering. The bodies of the serpents cross at the end of the stone, and each tail ends in three rattles. Fragments of effigy incensarios lay between the legs of the stucco figure; the legs, like the arms, extended well beyond the stone and were modeled over small unshaped rocks. Four shell and two jade beads were lying beside the figure, two burnt jade beads were in a broken incensario buried between the legs, and two more jade beads and a fragment of copper lay under the carved stone. It is impossible to say what deity was represented, but the combination of Maya and Mexican motifs is particularly interesting, especially since this figure was in use at the time of the abandonment of the city.

Of the other structures in the group, H-12, -15, and -16 are typical Mayapan colonnaded halls, each with two rows of columns, back and side benches, an altar in the rear, and a beam-and-mortar roof. In all three, there were heavy concentrations of incensario sherds in front of the altars. Only H-12 has attached to it a house (H-11), which seems to represent the building usually associated with colonnaded halls, presumably to provide service. This hall differs from the others in not being approached by a staircase; together with H-11, it stands on a separate knoll or terrace outside the plaza. Like H-15, it has a single transverse room, apparently a late addition. One of its columns is replaced by a rectangular pier. Structure H-15, the largest of the three, is approached by a very wide staircase with massive balustrades. Its transverse room is almost completely filled by a bench. A number of stones carved with designs of the Puuc period were scattered at one end of the main room, and in front lay a stone carved to resemble a sacrificial stone borne on the back of a crouching animal. It apparently was not in place. The third colonnaded hall, H-16, is badly destroyed, partly as the result of the removal of stones both before and after the fall of the roof. It was possible to ascertain that it had undergone extensive remodeling, probably more than once. Both the back row of columns and the rear benches had been moved forward. In the latest period, the benches in the

main room were faced with plain and decorated stones of Puuc type, so arranged as to form a simple design. There was a transverse room at each end, and the south one was approached by its own staircase. This latter room seems to have had a thatched roof, though the rest of the hall had a beam-and-mortar roof, and the presence of metates and plain coarse ware in this room may indicate that some of the household activities often confined to a separate structure were performed here. Exploration in the altar of this building and in that of Structure H-12 failed to reveal any signs of a cache, but in both cases breaks in the plaster tops of the altars may indicate looting. In front of the south room, on the level of the plaza floor, a tiny three-sided structure, H-16a, faced west. It contained only two low stone-and-plaster steps, but the broken parts of a grotesque stone figure found near by may indicate that the shrine once held an idol. A round altar lay on the ground beside the shrine. There were no offerings in evidence.

The other major building, H-14, lies on the west side of the plaza. Like all the structures in the central group, it has its own platform, but in this case the platform is so low that no stairs were necessary. The building, which shows signs of remodeling, is similar in plan to Structure H-17. It has a triple doorway formed by two columns and jambs, two interior columns, and back and side benches. The building is in such a state of disrepair that it is impossible to ascertain if there was an altar in the rear; there was no particular concentration of incensario sherds in the building. Fragments of human bone were found outside it.

Little is left of the remaining structure, H-13, but its square platform; and the scantiness of the debris indicates that if a building ever stood on top, it was made of perishable materials. The small structure stands at an angle in the northwest corner of the plaza and has a balustraded staircase on its southeast side. Off center in the platform, and set at an angle to the platform, a narrow rectangular shaft reaches down 2 m. It contained the badly scattered and decayed bones of at least three adults and one child. Again there were no grave goods. There were indications that a niche on the stairs may once have held a stucco figure.

Itzmal Ch'en seems to have been a secondary and minor center of worship at Mayapan. The fact that the annual rain ceremony of Telchaquillo is still performed at this cenote (see Year Book No. 51, 1951–1952, p. 250) may indicate the nature of this worship. In addition to its smallness and the apparent lack of much rebuilding and remodeling, Itzmal Ch'en differs from the Main Group in that there is no indication of the burning of buildings and no positive evidence for looting of caches, whereas the beads on the surface of Structure H-18a seem to show that it was not looted. The destruction of the statuary may or may not have been deliberate. Both Structures H-16 and H-17 have certainly been dug in, but it is impossible to say when or by whom. In types of structures and artifacts, such as stone turtles and effigy incensarios, Itzmal Ch'en does not differ from the Main Group, and it is possible that it escaped depredation, if indeed it did, simply because of remoteness. As elsewhere in Mayapan, there is extensive re-use of stones, seemingly of the Puuc Period, but no sign of the buildings to which they once belonged.

Excavations in Mayapan

Edwin M. Shook

A period of two weeks was spent at Mayapan during the 1955 field season investigating a small round temple, Structure Q-126. This unit, the best preserved of the four round temples at Mayapan, was selected for repair and solidification. The latter work was carried out by Strömsvik (see next section).

Structure Q-126 is situated on the eastern periphery of the concentrated ceremonial group of structures surrounding

the Temple of Kukulcan or Castillo (Structure Q-162), and lies on the north edge of what appears to be the main avenue of approach from the east to the heart of the city. As with the majority of buildings in Mayapan, only a few architectural features were discernible above the fallen mass of rough stone. The partly exposed western walls of the platform and temple provided the initial knowledge that a round building rested on a raised rectangular platform. The excavations included the complete clearing of the temple, the exposure of the west and south sides of the substructure, and minor trenching into the latter for earlier structural phases. The trenching disclosed three plaza floors and a small rectangular temple or shrine predating the round temple, but still built within the Mayapan Period. This earlier building and the floors were later buried by the relatively high substructural platform of the round temple. A broad stairway, flanked by plain ramp-type balustrades, on the south side of the platform gave access to the frontal terrace of the temple. Here evidently stood a line of plain and carved stelae before the temple doorway. Fragments of two plain stelae remained on the terrace, and both plain and sculptured monuments lay at the southern base of the platform, seemingly fallen from the terrace. The temple is a duplicate in plan of Structure Q-214, previously reported (Year Book No. 53, pp. 272–273), with a round outer wall enclosing a space divided in half by a medial partition. A single doorway on the south provides access to the first small chamber; another in the medial wall gives entrance to the rear room. The temple's lime concrete floor showed heavy staining from considerable burning, concentrated on a north-south line from the outer doorway and increasing toward the rear chamber. In addition, a layer up to 15 cm thick of ashes and charcoal mingled with pottery censer fragments covered the floor. Against the rear wall, opposite the doorway, an irregular, circular patch where the floor was missing marked an area heaped with ashes, charcoal, and censer fragments. If a masonry altar once stood against the rear wall, it had been ripped out before the heavy burning which took place in the back room.

The evidence of incense burning within the temple, the accumulation of pottery censer fragments around the base of the substructure (apparently sweepings from the temple and terrace), the secondary addition in the center of the substructure stairway of a tiny shrine room containing a modeled stucco idol, and the many associated stelae, all point to the importance of Structure Q-126 as a temple for ceremonial rites. The striking similarity of Structures Q-126 and Q-214, in all but minor details, suggests that the two temples served identical functions. The fact that one faces south, the other east almost certainly precludes their use for astronomical purposes.

The pottery recovered from Structure Q-126, from the excavations by Chowning and D. E. Thompson in the ceremonial group at Itzmal Ch'en, and from the digging in Group Z-50 by Pollock was analyzed by Shook during the past season. The major portion of his time was devoted to the general study of the pottery of Mayapan for a forthcoming report.

Exploration and Reconstruction in Mayapan and Vicinity

Gustav Strömsvik

During the first part of the field season Strömsvik assisted Chowning and D. E. Thompson in their digging for building plans and architectural details at Itzmal Ch'en. The results of these excavations are reported by Chowning.

In conformity with our policy of consolidating certain representative buildings at Mayapan, Shook cleared the round structure Q-126, 200 m east of the Castillo, at the beginning of the season. Early in March the consolidation of the rectangular substructure was started. The entire west side was taken down, to be relaid in

lime mortar, except for a section at the north end, where a joint between this and an earlier structure was plainly visible. Good lime-mixed mortar was still there between the stones, and the wall was undoubtedly as straight as the ancient builders had left it. In this section the cracks were filled with cement and chinking, without moving the stones. At the south side, the stairway was partly rebuilt as high as the sixth step, and the balustrade stones were reset as far as they were found. Also, a small shrine in the middle of the stairway was solidified to the extent that it was found. In examining the round building on top, it was discovered that the wall contained much of the original mortar. Only the outer facing of this part of the construction was reset in fresh mortar; the cracks between the stones in the inner facing were chinked with mortar without taking the wall down. The inner doorjambs were reset to the height found when they were excavated, as were also the outer doorjambs. The tops of the walls and the cracks in floors and stairs were sealed with rich cement mortar. A small, broken stela was repaired and set upright on the west side of the substructure, and at the east side a small, much damaged stela with faint traces of hieroglyphs was laid leaning against the rubble on the unexcavated east side of the substructure.

In addition to this work of repair at Structure Q-126, it was planned to solidify the existing remains of a city gate and a section of the city wall to give an impression of how the Great Wall of Mayapan had once looked. Gate D, 400 m east of the Telchaquillo-Tekit road, was chosen as a good example. This gate had been partly excavated in 1952 (Shook, 1952, C.I.W. Current Report 2, pp. 10–12). A stretch of wall just west of the Telchaquillo-Tekit road was thought to be both representative and easily accessible to visitors, and this section was restored to its original height, with a plaster floor on the banquette, according to the evidence found. By the end of May all work of consolidation was finished.

Some months earlier natives of Telchaquillo had told Strömsvik about a cave near the town of Tecoh, about 10 km north of Mayapan, called Dzab-Na ("house of rattles"), where, according to legend, the remnants of the Mayapan people took refuge when their city was destroyed. This cave seemed worthy of investigation, and in June this was undertaken. Using a small lighting plant and all available electric cable, the center area, about 100 m in diameter, was investigated and mapped. Three cenotes were seen in the cave, but the natives say there are seven. A good quantity of potsherds was found, but no stratigraphy, there being no depth of soil. Even so, one can say that the cave floor was strewn with typical Mayapan wares, underneath which were found quantities of Slateware. Fragments of classic Maya polychrome were also seen. A discovery of particular interest was a statuette of polished black wood. The seated human figure, about 15 cm high, is remarkably well preserved. Articles of perishable materials are of course extremely rare, and any such finds come as more than welcome additions to our knowledge of the ancient arts and crafts.

Pottery of Mayapan and Vicinity

Robert E. Smith

The number of potsherds collected at Mayapan during the 1955 field season approached 200,000. This collection amplified rather than changed the picture as shown in last year's report. A few results, however, are significant. Effigy-type incense burners were more than twice as abundant in and around ceremonial structures as they were in association with dwellings, whether the dwellings were of elaborate or simple type. The smaller number of incense burners found with house mounds was offset by the increase in Mayapan Red and porous gray wares. Mayapan Red-on-buff or Red-and-black-

on-buff pottery, never found in large percentages, was three times as abundant in house mounds as in ceremonial structures. Black-on-cream ware was twice as abundant in ceremonial structures as in the more elaborate dwellings; the ordinary house mound rarely harbored any black-on-cream sherds. There is still much to be learned from a careful study of the pottery associated with different types of structure, and even of the pottery from functionally different rooms within structures.

The pre-Mayapan Period material found at Mayapan amounted to less than one per cent. It was outside the city that early potsherds abounded. In a survey of small outlying sites, usually close to cenotes, sherds were picked up within the cenotes as well as from the surface outside. This collection totaled nearly 3000 pieces, of which 42.2 per cent were of Puuc or lowland Maya Classic type and 1.1 per cent were pre-Classic. Many of these sites had colonial sherds (12.4 per cent). Actually, save for a few fragments of effigy incense burners and even fewer Mayapan Red-on-buff sherds, the Mayapan Period was poorly represented.

Explorations on the East Coast of Yucatan

William T. Sanders

This season Sanders continued his ceramic survey of the east coast of Yucatan. The previous field season had been spent in a general survey of the coast from Holbox to Tulum, and included small test excavations for ceramic samples at thirty-seven sites. The pottery indicated a great abundance of sites of the Mayapan Period and a few sites of the Classic Period. This year it was decided to concentrate on two major sites, Tulum and Tancah, within the area mentioned. These were selected as important centers for the Mayapan and Classic Periods, respectively, and it was hoped that extensive testing at both would enable us to break down each period into phases. Aside from ceramic differences, the two sites show important distinctions in architectural style, and by ceramic testing it was thought that some idea of the development of the East Coast architectural style might be attained.

A crew of workers was brought from Kantunil Kin to Tulum to carry on the excavations, labor being completely lacking in the latter area. A total of three weeks was spent at Tulum, and over forty trenches were excavated in and around all the major buildings. In general these were dug along the edges of temple and palace platforms, usually in the vicinity of stairways. A few trenches were excavated in buildings, mainly involving small platforms rather than major structures. Several rooms were cleared of roof and wall debris to get above-floor samples.

The average depth of soil and cultural deposit at Tulum is very shallow, the deeper deposits, 50–100 cm, occurring in and around Main Street, which crosses the city from the west gate in the north wall to the west gate in the south wall. On the rocky knolls which underlie the Inner Enclosure, Cenote House, Temples 45 and 54, and slopes in general, sherds are often found on bare rock, and at most the soil depth runs from 10 to 30 cm. In spite of these conditions, excellent sherd samples were obtained in the vicinity of all major structures. The trenches indicate clearly, by the absence of extensive floor construction, rebuilding, and gross depth of cultural deposit, that the period of occupation at Tulum was extremely short, probably not exceeding a few centuries.

Six weeks were spent at the site of Tancah. Here the situation was quite different. Excavations were conducted in Groups A and B, with those in the former yielding best results. Excavations in Plaza A revealed a complex succession of paved floors running from three to seven in number, and samples of pottery were obtained from a number of these levels. On top of the first floor and in the top soil layer, typical Tulum Period censer wares were found, but all the pottery below floor levels

is Classic in date. Extensive trenching in the vicinity of the two major groups indicated an over-all soil-refuse depth of approximately 50–100 cm, with several trenches running to 2 m. Very little Tulum pottery was picked up in these trenches, a fact which indicates that the Tulum Period occupation of the site was ceremonial in nature. Lothrop's site map was considerably extended, and the new structures added—mainly platforms and a few temples—are at least equal in number to those mapped by him. Ceramic samples were also obtained from the platforms of the newly mapped temples.

On completion of the work at Tancah, operations were moved to the Chetumal area, where two weeks were spent testing two sites, the walled site of Ichpaatun, which is of the Mayapan-Tulum Period, and the Classic site of Calderitas. Both have been reported and described by Escalona Ramos. Excellent ceramic samples were obtained from each site, especially the former.

Preliminary analysis of the ceramic material indicates the following important points. Tulum is the largest post-Classic site seen during the two seasons spent on the east coast; it seems to be entirely of the Mayapan Period. There are four basic local wares. First, there is a red slipped ware, which in general is very close to Mayapan Redware, although with finer paste and better surface finish. It occurs in three definite forms: tripod plates or bowls, tripod molcajetes or chile grinder bowls, and jars, all three shapes showing close linkage with those at Mayapan. Secondly, there are several types of censer wares, at least two of which are exact duplicates in form of Mayapan censers. Thirdly, there is an unslipped ware running entirely to jars which show a close resemblance in lip and neck form to their Mayapan counterparts. The fourth ware, found in very small quantities, is the northern Yucatan black-on-cream. Fine Orange occurs as a light but consistent component and seems to be entirely of Berlin's Tamulté type. No plumbate was found.

There appears to be slight possibility of breaking down our Tulum Period into phases; it seems to represent a short period ceramically. Spatially, Tulum pottery has a considerable range, especially the red and censer wares. Both occur along the coast from Holbox to Tulum, and the pottery from Ichpaatun in the Chetumal area is almost a duplicate of Tulum pottery. Good representative sites other than Tulum are Cancun Island, El Meco, Chiquilá (Period 2), and San Gervasio on Cozumel Island.

The Classic Period along the east coast is not so easily defined. There seems to be fairly good evidence allowing a breakdown into an Early Classic stage with strong Peten influences (Tzakol), followed by a cessation of Peten influence in favor of that from the Puuc region. The pottery from Tancah should help toward clarifying this problem. The above statements refer strictly to the Holbox-to-Tulum region, the situation in the Chetumal area probably being quite different.

One interesting problem is the representation of the early post-Classic or Toltec–Chichen Itza Period on the east coast. A number of sites excavated last season seem to fall in that time period in part, although lacking the diagnostic ceramic and architectural manifestations found at Chichen Itza. The period seems to be characterized on the east coast by a continuation of the Puuc Slateware tradition, with the addition of a distinctive local ware called by Sanders Vista Alegre Striated, after the site where it occurs in heaviest concentration.

Aside from study of ceramic stratigraphy, extensive testing, including mapping and excavation, was carried out at Tulum and Tancah to obtain data on settlement patterns.

At Tancah, trails were cut at 20- to 40-m intervals, forming a grid pattern covering an area 540 m north-south by 600 m east-

west and extending in all directions around the two mapped plazas. A careful search was made of all squares to map structures, whether religious or domiciliary in character. Secondly, trenches were excavated at most of the intersections of the grid trails to get an idea of the depth and quantity of habitation refuse and its distribution over the site. These trenches were all of uniform surface area (1 m by 1.5 m) and were carried to bedrock. Some 180 trenches were dug, and they gave an excellent idea of population distribution. A preliminary study of the data indicates the following conclusions:

(1) There are few heavy refuse deposits anywhere at the site. Good deposits almost invariably occur just off temple platforms or house mounds. There are large areas of little to no cultural deposition between plazas or house-mound clusters. (2) It seems almost certain that a good estimate of the population maximum of the site may be obtained on the basis of the house-mound count alone. (3) The site is curiously overbalanced; there are as many buildings of purely religious function as there are domiciliary platforms, and the total of house mounds does not exceed a few dozen. (4) Almost all the house platforms are very large, often running 40–50 m in length, and are quite obviously not remains of dwellings of a proletariat. (5) We seem to have at Tancah an important religious center with a small resident elite population, probably not exceeding a few hundred persons, in other words a typical ceremonial center as described by Torquemada for the lowland areas of Mesoamerica in general. (6) In the interior for a distance of several kilometers there are scattered through the forest small groups, each consisting of a small pyramid or two surrounded by six to twelve house platforms; apparently these were small agricultural hamlets of the type mentioned by Gaspar Antonio Chi in *Relaciones de Yucatan.*

At Tulum the situation seems to be quite different. In spite of the lack of soil and much shorter period of occupation, Tulum has much more cultural refuse in general, and many more good ceramic dumps. The area enclosed within the main wall is approximately 450 m north-south by 200 m east-west, or approximately 9 hectares or 22 acres. Of this total, approximately 3 hectares are occupied by purely religious structures or by large palaces. The rest of the enclosed space, that lying west of Main Street and the section east of Main Street which lies south of the Inner Enclosure, shows abundant surface indications of a dense nucleated population. The area lying south of the Inner Enclosure and east of Main Street is sharply sloping, and the slopes are worked into a series of terraces to provide locations for dwellings. House mounds are rare, the population evidently having lived in pole-and-thatch dwellings directly on the terraces of the slopes, or directly on bedrock in more level areas. Approximately seventy trenches of the type excavated at Tancah were made here. The results of these excavations checked the conclusions reached on the basis of surface remains. The indications are that we have a settlement pattern similar to that found at highland Mexican sites, an interesting fact in view of the strong highland Mexican influence in architecture and pottery at the site. One is, however, surprised at the small area urbanized, considering the number of religious structures and the importance of the site. The reason lies undoubtedly in the deficiencies of slash-and-burn agriculture as an economic basis for true urban society.

The entire area enclosed by the southern extension of the west wall is notable for the almost complete absence of refuse deposits and structures. It probably served as a refuge for the surrounding farming population in times of attack. Outside the walled areas there is no evidence of urbanization. An interesting discovery was made in the survey of the area south of the site. The forest just south of the walled area is crisscrossed by an amazingly complex system of defensive works, involving inter-

secting walls, double walls, and walls with parapets, which runs into the bush for hundreds of meters. Unfortunately, time did not permit mapping, a task which should be done within a few years, as the walls are in an advanced state of destruction.

Yucatan and Chiapas

Edwin M. Shook

Except for the brief time occupied by field activities at Mayapan (see above), Shook spent the major portion of the past season in Merida. There, at the Department's ceramic laboratory, he studied the pottery of Mayapan, assisted Berlin with his report on Tabasco, and recorded a number of privately owned archaeological collections. Shook also devoted about five weeks to exploration of ruins in the environs of Merida, on the coast of Campeche, and in the central highlands of Chiapas.

The private collections in Merida range in size from several specimens to over a hundred, usually of pottery, recovered from sources widely dispersed throughout the Yucatan peninsula. Though often lacking important information on exact provenience and association, these collections provide complete examples for study of many ceramic types previously known only from sherds. In rare instances, the contents of a single tomb or grave have been retained by the collectors, and in such cases contemporaneity and cultural relations may be established from association of pottery types.

Within the modern city of Merida and on its outskirts, the last vestiges of the preconquest settlements are fast disappearing. The ancient structures are being demolished to clear space for new factories, houses, streets, and the like, or because the archaeological mounds provide a more readily accessible supply of building stone than do the quarries of native limestone. An effort was made to map, photograph, and collect sherd samples from as many of the archaeological sites as time permitted. The following ruins were briefly visited and recorded.

Tecoh is situated on the lands of Hacienda Tecoh, 6 km south of the central plaza of Merida. Twenty or more ancient house mounds and low platforms, several rectangular mounds 2–3 m high, and one pyramidal structure approximately 8 m high are arranged around a cenote with a permanent water source and a spacious natural cave. The cave, now dry, may once have had a shallow pool of water, but its principal use appears to have been for quarrying sascab (lime gravel) for building purposes. The ancient quarrying on the cave's east side created a low-ceilinged chamber fully 25 m in diameter. The entrance from the natural cave to the large artificially dug chamber had been closed by a thick stone wall except for a single narrow, low-roofed passage. A search by flashlight of the pitch-dark room resulted in the recovery of only a few potsherds around the floor edges and near the entrance passage. Outside, on the cave floor and in the fill of a collapsed part of the masonry wall, were potsherds in abundance. An unselected surface collection included a few pre-Classic, a preponderance of Early Classic, and several Late Classic and Early post-Classic sherds. Among the latter was a decorated spindle whorl similar to some from deposits of the Toltec Period at Chichen Itza.

The cenote has a roughly circular orifice and a rocky floor sloping down to a deep pool of water about 20 m from the entrance. A well-worn path with a few artificially cut steps leads to the water's edge. Along one side of the path, crudely sculptured in the natural rock, is a grotesque writhing serpent.

The Tecoh mounds, now almost entirely robbed of facing stones, are identified by featureless heaps of small dry rock fill. A careful search among the rock piles disclosed that Late Classic Medium Paste Slateware sherds predominate over other pottery types, though pre-Classic and Early Classic types are present. A few scattered

cut and dressed wall stones also suggested that the major occupation of the site was during the Late Classic Puuc Period.

Quinta Miraflores is apparently a small site, as remnants of only three mounds remain. The ruins are located in the gardens 100 m east of the main house of the property called Quinta Miraflores, 4 km east of the central plaza of Merida. The present small acreage of the quinta is surrounded by a residential section which formerly was a part of Quinta Miraflores. Two of the archaeological mounds have been reduced by quarrying to barely discernible outlines, but the third retains some architectural features. The local people report the last to have been approximately 10 m high before quarrying brought it to its present height of 1.5 m. Exposed are vertical and sloping terrace walls, lime-plastered stairways, and floors of four successive building stages. The structure in each stage apparently had been a rectangular platform, with steps on either the east or the west side, supporting a building of perishable material. There was no evidence of vaulted masonry buildings. Substructure walls were built of rough uncut stones, then surfaced with lime plaster. A collection of 900 potsherds was obtained from the fill and general debris of the mound. The majority of the sherds were derived from a midden of charcoal, ash, bone fragments, and so on, outside and at the base of the second-phase platform. This midden appears to have been normal household rubbish thrown over the edge of the platform.

The entire sherd lot from this Quinta Miraflores mound belongs to the pre-Classic Period and conforms particularly well with what has been termed the Late Formative stage. There are no identifiable unslipped wares even among the high percentage of jar sherds, nor are there jar handles. It is significant that jar handles are lacking in all pre-Classic material Shook has examined from northern Yucatan. Among the 900 sherds, one from a flat-bottomed, low flaring-walled bowl shows the mark of a foot attachment. It could not be determined whether the secondary support had been a solid nubbin or a hollow foot. The evidence from Quinta Miraflores clearly demonstrates simple but formal architecture with four successive rebuildings of the same unit during a late phase of the pre-Classic Period.

Colonia Miraflores is an archaeological site of at least six mounds from 1 to 4 m high, 0.5 km south of Quinta Miraflores on lands formerly belonging to the same property. The area, on the southeast edge of Merida, 4 km from the central plaza, is now a real estate development called Colonia Miraflores. The ancient structures, just north of the highway to Kanasin, are being demolished for building material. In several there are lime concrete floors exposed at different levels, showing a sequence of building activities. In the mound debris are a few well-cut and dressed wall and molding stones and colonnettes of types commonly associated with Late Classic Puuc-style vaulted buildings. The pottery and stone artifacts from the surfaces and fill of the mounds indicate a long period of occupation, extending from the pre-Classic, through the Classic, into the Early and the beginning of the Late post-Classic Period. The majority of the sherds and several restorable vessels are of Medium Paste Slateware, confirming the architectural evidence that the site flourished mainly during Late Classic Puuc times.

Tihoo is the major pre-conquest site over which is built the central part of Merida. Further information was gathered during the past season from oral and written sources and personal observation regarding the distribution of archaeological mounds around the center of Merida. Only the larger structures have been recorded in published sources or are remembered by living inhabitants. Of the many units, traces of four exist today. The collection of pottery from the Franciscan monastery mound, made by R. H. Thompson and Shook in 1951 (see Year Book No. 50, 1950–1951, pp. 236–237), was re-examined.

Among the pre-conquest material, there were no sherds identifiable as pre-Classic, and just a few Early Classic ones. The majority are Late Classic Medium Paste Slateware, several are attributable to the period of Toltec influence in Chichen Itza, and a fairly sizable lot are black-on-cream, a common ware in the earliest levels of the Mayapan Period. The absence of Mayapan Redware sherds in the Tihoo collection suggests that black-on-cream may have been produced in northern Yucatan before, and continued in vogue for some time after, the development of Mayapan Redware.

Xcanatun is a major archaeological site 16.5 km north of Merida and 0.5 km west of the highway to Progreso. The location of the ancient settlement had been well chosen for water supply, as four small cenotes exist within the confines of the ruins, each opening to the shallow water table approximately 2 m below ground level. The continued ruthless destruction of this great site for road building fortunately was stopped this year through the energetic protests of Dr. Alberto Ruz L., Government Inspector of Ruins for Yucatan. The foundations of six major structures at Xcanatun are recognizable, as well as numerous lesser mounds and platforms. The local workmen reported that the largest unit, before quarrying began, stood 20 m high and measured 80 m square at the base. The structures are formally arranged around several rectangular plazas, the principal one being elongated with its long axis north-south. Throughout the site and on the periphery are many low terraces or platforms retained by walls of large uncut stones laid without mortar. These terraces presumably supported houses of perishable material. There was no cut building stone or sculpture around these terraces or in the debris of the partly destroyed larger central structures. The latter had terrace and free-standing walls exposed, but no evidence of Maya vaulting. Room walls, though heavy, apparently supported beam-and-mortar or thatch roofs. Walls were constructed of rough, undressed stones and were smoothly surfaced with lime plaster. Floors of rooms, terraces, and plazas had been finished with a hard white to salmon-color lime concrete. Each major structure showed many successive rebuildings, suggesting a relatively long period of development.

Pottery collected from the fill and debris of the larger mounds, including a restorable jar containing an infant's skeleton, proved to be entirely pre-Classic. A few of the sherds conform to types recovered at Quinta Miraflores, but most of the material suggests a ceramic phase older than Quinta Miraflores. A single low mound, partly cut away, had in its debris weathered fragments of an Early Classic lustrous monochrome jar, and on the surface away from mounds were a few weathered sherds of Late Classic Medium Paste Slateware and Fine Orange. The ceramic and architectural evidence demonstrates that Xcanatun flourished as a major center during the pre-Classic Period.

Soblonké, a small site 9.2 km north-northwest of Merida, on the south edge of the highway to Sisal, lies at the southeast edge of the village of Caucel, which is built on and around another archaeological site (Year Book No. 50, pp. 233–234). The ruins consist of six low mounds from 0.5 to 1.5 m high and a larger structure 3.25 m high. The last has been sectioned by quarrymen, exposing vertical and sloping substructural walls built of rough, uncut stones and surfaced with lime plaster. The construction is of the same type as that at Quinta Miraflores and at Xcanatun, and again only pre-Classic pottery comes from the mound fill and debris. The workmen quarrying the mound had encountered, just before Shook's visit, a burial of a male adult beneath the lowest floor and just above bedrock. They described the position of the skeleton as extended with head to the east. The several pottery vessels accompanying the body had been smashed by the workmen's picks, but many of the fragments were recovered.

These were flat-bottomed bowls of large diameter with heavy, straight flaring walls and with all-over glossily polished, crazed monochrome slip. The colors range on the same bowl from red to brown to black where fire-clouded. These vessels and sherds conformed to the principal types found in the major structures at Xcanatun. A few sherds of Medium Paste Slateware were encountered on the ground surface at Soblonké.

Tuc is a small site 5 km north of Caucel and approximately 10 km northwest of Merida. Except for stone-robbing for fencing the henequen fields surrounding the site, the ruins of Tuc have not suffered such extensive damage as the sites previously described. A single pyramid, 12 m high, dominates the site and occupies the west side of a small plaza with lower temple mounds or platforms on each of the other three sides. Low mounds and terraces surround this ceremonial nucleus for several hundred meters. The pyramidal unit retains traces of a stairway on the east side, terraces of rough stone masonry, and the base courses of the temple's back wall. The position of the wall and of uncut stone masonry on the pyramid summit suggests a single-room temple facing east. Elsewhere at Tuc only one cut and dressed building stone was observed; it lay in the debris of the platform closing the north end of the central plaza. No pottery could be found on the surface. The placement of the principal occupation of Tuc in the Classic Period, on the basis of site arrangement and the few architectural details, is little more than a reasoned guess.

Ucu, a site consisting of a single mound 8 m high in 1951 (see Year Book No. 50, p. 234), has only traces of the mound left. All except the southern fringe has been torn down to bedrock. The destruction since 1951 disclosed that the structure contained an important architectural and ceramic sequence beginning with a pre-Classic unit with rough uncut stone masonry walls, probably a rectangular platform. How many rebuildings of the primary unit took place could not be determined, but eventually the whole was buried by an Early Classic pyramidal substructure with a stairway on the south side. This unit also probably underwent successive increments before the final Late Classic Puuc-style structure was erected over the older building. Remnants of the vaulted Puuc-style temple atop the pyramid were observed in 1951. Walls were faced with cut and dressed veneer stones set in excellent lime mortar and surfaced with a thin, hard lime plaster.

The small sherd sample collected in 1951 from the Ucu structure was considerably enlarged during the past season. Though hopelessly mixed from surface to bedrock by the quarrying operations, the material could be segregated typologically by comparison with controlled collections from Yucatan. Pre-Classic types comparable to wares found in Xcanatun and Soblonké were relatively frequent. Early and Late Classic types were almost equally well represented, the best diagnostics being Lustrous Monochrome jars and Medium Paste Slateware.

The above information, coupled with that gathered in previous field seasons, may be summarized as follows. The small area encompassed by the city of Merida and its immediate environs contains architectural and ceramic evidence of considerable population, possibly continuous, from pre-Classic (Middle Formative?), through Classic, into post-Classic times. The earlier phases of pre-Classic, and the final period before the coming of the Spaniards, most of which was the time of political dominance of Mayapan, are lacking in the Merida area. That no remains of these phases have come to light is probably due to the paucity of search by archaeologists. The brief catch-as-catch-can survey of the past season has broadened our knowledge of the pre-Classic Period in northern Yucatan and demonstrated that large and small sites with permanent stone architecture of ceremonial, civic, and probably domestic nature flour-

ished long before the so-called florescence or Classic expression of Maya culture.

A brief exploration by motor launch was undertaken along the west coast of the Yucatan peninsula from Campeche to Sisal. Archaeologically this coastal strip north of the Island of Jaina is known only to professional pot hunters and a few fishermen living in widely separated villages. The following sites were visited.

Jaina, 36 km north of Campeche, had previously been visited by the writer (see Year Book No. 50, pp. 239–240). This time a more thorough study was made of the limited habitation area on the island. Tightly concentrated around the temple mounds, and interrupting what normally would be an open plaza between major public buildings, were low rectangular house platforms. These were faced with vertical walls of cut and dressed block masonry, the same as that used in the pyramid terrace walls. Adjacent to these house platforms, pot hunters' pits disclose up to 2 m depth of household refuse, heavily sown with human burials. Often a skeleton, either of a child or of an adult male or female, is buried tightly flexed in a large pottery urn. The stratigraphy clearly shows that many of the urn burials were inserted into pits dug through old, horizontally bedded refuse; others were sealed by postburial deposits. Grave furniture may include small ornaments of jade, artifacts of shell and bone, pottery vessels, and figurines, figurine whistles, flutes, and drums of pottery. The articles, if space permitted, were placed with the body inside the urn; otherwise, offerings were laid around the outside of the containing vessel. The rubbish accumulation, evidently from households, contains ash and charcoal lenses, quantities of broken pottery predominantly of coarse unslipped utilitarian wares, fragments of manos, metates, obsidian flake blades, and chipped chert blades, and animal, bird, and fish bones. The inhabitants of Jaina evidently preferred refuse deposits around the house for interment of their dead, or else no other suitable ground was available. Certainly the tiny island was thickly populated during Late Classic times. No earlier material has so far come to light, and only an occasional surface fragment indicates habitation after the Late Classic Period.

Isla de Piedra, approximately 8 km north of Jaina, is a small island about 200 m in diameter barely detached from the mainland. The land area rises gradually from a mangrove swamp next to the mainland to a 5-m cliff on the ocean side. The small archaeological site, of about a dozen house platforms and low mounds concentrated around courts, is on the west half of the island. Numerous pits have been dug by treasure hunters. Pottery and artifacts, the former severely weathered, occur in abundance in the upper 30 cm of the site and sporadically to 50 cm depth. The eroded condition of the sherds permits only a provisional suggestion that Isla de Piedra may have been a short-lived coastal village at the beginning of the Late Classic Period.

Huaymil, 8 km north of Isla de Piedra and 16 km from Jaina, is a small island clump of mangrove opposite the mouth of the Rio Huaymil. The ruins lie on the north bank of the river, 2 km inland from the sea, on the first land sufficiently elevated to permit habitation. Mangrove swamp extends from the archaeological site to the sea. A thorough exploration of Huaymil was not possible in the time available. The ruins are enveloped in part by dense, low jungle growth, in part by tall savanna grass. Shook was able to observe only what he believes to be the western edge of the site. Here a series of tightly enclosed courts are surrounded by colonnaded buildings, some vaulted, and temple structures on high, steep-sided pyramids. One pyramidal mound 12 m high apparently faced north to a court on the edge of which stands *in situ* the bottom third of a carved stela. The upper two-thirds of the monument is missing but may lie buried in the surrounding debris. The stela, of fossiliferous limestone, is plain on

the back and the two narrow edges, but the front bears a framed panel containing a standing human figure with feet pointing outward. One partly exposed colonnaded building has a triple entrance formed by two columns, each a single stone reaching to lintel height. The doorjambs and lintels also are single, full-width stones, and the walls are faced with moderately well cut and dressed stone. The structure has two long parallel vaulted galleries with four or more columns acting as medial supports.

The pottery collected from the back-dirt of pot hunters' excavations and from the general surface of the site is predominantly Early post-Classic. Well represented are typical wares and forms commonly found in Chichen Itza during the period of Toltec influence. These are "X" Fine Orange and Chichen Medium Paste Slateware jars and bolster-rim basins. The sherd sample contained no Tohil Plumbate, but in a private collection in Merida, reported to be from Huaymil, there are a number of whole Tohil Plumbate and "X" Fine Orange vessels.

Huaymil may have been an important Maya center with stelae and Puuc-style architecture at one time, and later, during the Early post-Classic, have come under the same Toltec influence that dominated Chichen Itza.

North from Huaymil along the coast past Isla Arena, no archaeological site with mounds was known to the local fishermen questioned. They all mentioned Punta Canbalam, about 6 km north of Isla Arena, as a place where pottery was abundant. This information proved to be correct.

Canbalam is a long, narrow beach of unconsolidated seashells that is separated from the mainland by an estuary and mangrove swamp. The maximum elevation is 1 m above sea level, and the beach is frequently submerged during storms. Strewn for at least 1 km north-south along the white beach and embedded among the shells to sea level are quantities of waterworn potsherds and stone artifacts. The amount of pottery precludes any possibility that Canbalam was a seasonal camp site, and against such a supposition, too, is the lack of fresh water and the precariousness of existence on a low beach exposed to storms. An alternative theory to explain the heavy deposit at Canbalam is that the point once was much more extensive and higher, like Isla Arena, Isla de Piedra, and Jaina, and had an adequate source of fresh water, and that a sizable ancient settlement occupied this point of land. Centuries of wave action may slowly have cut away the land area and left today just a narrow low strip on the inland side with a fringe of refuse deposits from the old habitation area. The recognizable sherds in the collection from the beach were Late Classic types, including Fine Orange.

The sandbar beginning south of Celestun and paralleling the mainland around northern Yucatan reportedly has shell mounds, but Shook saw none from Celestun to Sisal.

Late in the field season the opportunity was taken to join, in an advisory capacity, a survey expedition into the central and eastern highlands of Chiapas, Mexico. The objective of the expedition, sponsored by the New World Archaeological Foundation, was to locate pre-Classic sites for future intensive excavation. Considerable information was gained in this archaeologically little-known region, particularly in the drainage of the Rio Grijalva. The previously reported ruins on the east bank of the Grijalva at Chiapa de Corza were found to be a major site, many of whose large structures were erected during the pre-Classic Period. Upstream about 40 km from Chiapa de Corza a concentration of archaeological remains was encountered along both sides of the Rio Grijalva, centered around the modern town of Acala. Most abundant were pre-Classic and Late Classic sites, though it is likely that further investigation will disclose Early Classic and post-Classic remains.

The Acala region is characterized by rolling to mountainous topography sectioned by the Rio Grijalva. On each side of the

river there are a number of small, level, exceedingly fertile terraces which have been built up of river-deposited silts from repeated flooding. The level of these terraces is about 12 m above the April 1955 water level. In geologically recent time the flood deposition stopped, and the Grijalva has since cut its present channel, leaving exposed sections of the silt terraces. A study of these river banks revealed cultural material of pre-Classic date in the upper 4 m of soil, and Late Classic remains which were limited to the surface level except where deposited in pits intrusively dug through the horizontally stratified silts.

A sherd-bearing, pre-Classic midden 30–75 cm thick was discovered deeply buried in the river bank opposite Acala, just below Puerto Mexico. An exposed cross section of the midden, 18 m wide, showed its east-west limit, but knowledge of how far the deposit extends into the bank must await future excavation. Shook sank a pit 2 m square, using the river bank as one side of the cut, in order to sample the midden, which lay 2.25–2.9 m below the present valley floor. The upper 1.7 m represented successively deposited layers of fine, sandy loam containing only a few eroded potsherds. This was followed by an occupation level, 1.7–2.0 m below the surface, composed of charcoal, ashes, sherds, and stone artifacts in a matrix of gray-brown sandy loam. Directly below was another distinct 25-cm-thick layer of light yellow-brown loam which effectively sealed over the midden first observed in the river bank. The cultural material from the 25-cm stratum conformed generally with that from the lower deposit and may have been contemporary surface rubbish washed over the midden during the floods which sealed the main deposit. The latter, in an area 2 m square, produced an estimated 8000 to 10,000 pottery fragments, besides typical midden material of ashes, charcoal, charred seeds, animal and bird bones, burned fragments of adobe bearing pole impressions, some shell, bone, and a quantity of stone artifacts.

This large body of unmixed pre-Classic material, probably representing a single phase, provides a datum of reference for future investigations in central Chiapas. The common pottery types were an unslipped coarse brown ware jar without handles and with a straight flaring neck to a direct rim, and an all-over slipped and polished red, red-brown to brown ware bowl with flat base and straight vertical or flaring wall to an out-curving or everted rim. A few small solid and hollow nubbin feet were found, and several larger hollow feet tapering to a flat bottom. Vessel decoration other than slipping and polishing was rare. Fragments of four hand-modeled figurines of pre-Classic type came from the midden. There were no comales, and only two uncertainly identified sherds suggesting incensarios.

Elsewhere in the Acala region samples of pre-Classic pottery were recorded, some stylistically predating and others postdating the Puerto Mexico midden types. Present in these insecurely anchored collections were vessels and sherds of white-rimmed black ware, a pottery found in greater abundance in the Olmec sites of Tres Zapotes and La Venta.

Two Late Classic Period sites, Cupia and Laguna Mora, in central Chiapas, are especially noteworthy because the ceramics of both indicate close trade relations with the Gulf coast plain of Tabasco and the central highlands of Guatemala. Also, sherds of San Juan Plumbate occur at Cupia and Laguna Mora, the farthest northwest this type of plumbate has yet been reported.

Southwestern Prehistory

Earl H. Morris

As my retirement comes with the end of the period covered by this report, it seems appropriate to review my long connection with the Carnegie Institution. That association began when the late S. G. Morley, then planning for the campaign of excavation and restoration that was to be under-

taken in Yucatan, selected me as general engineer and director of excavations for the Chichen Itza Project. Early phases of the work were the rehabilitation of the hacienda that was to serve as headquarters, the installation of light and water systems, and the construction of new buildings as the need for them arose. These necessary, but archaeologically irrelevant, activities were not permitted to interfere with the basic purposes of the undertaking. Excavations were begun as soon as the first field party reached Chichen Itza in the late spring of 1924. At the beginning of the 1925 season a crew of masons was added to the workmen, and thereafter excavation and repair were pressed forward concurrently.

The concession from the Mexican Government under which the Institution was permitted to operate named the Court of the Thousand Columns, in the northeast quarter of the city, as the principal focus of its activities. By the end of the fifth field season—May 1928—the northern side of the huge court had been freed of debris and repaired to the intended extent. Structures uncovered were the Northeast, the North, and part of the West Colonnade, and an imposing architectural complex at the northwest corner of the Court. This complex consisted of the Temple of the Warriors, the Temple of the Chacmool, an older structure much of which had been encased in the masonry of the pyramid supporting the Warriors, and the Northwest Colonnade, which flanks the western side of the Warriors pyramid. With this major unit completed, the winter of 1928–1929 was spent in collaboration with Jean Charlot and Ann Axtell Morris, preparing the detailed report that was to appear as *The Temple of the Warriors,* Carnegie Institution of Washington Publication 406. At the same time I was at work on a popular book, also called *The Temple of the Warriors,* which was printed by Charles Scribner's Sons.

In spite of my five seasons' work in Yucatan, I was more deeply interested in the archaeology of the Basket Maker–Pueblo area of the southwestern United States than I was in the Central American field. This fact caused me to decide to withdraw from Carnegie Institution in order to seek the backing of some organization that would permit me to resume my studies of the Southwest. At the crucial moment, however, A. V. Kidder became Chairman of the Institution's Division of Historical Research, and he was sympathetic to the suggestion that the Institution's program be widened to include the Southwest. This plan was approved by the late John C. Merriam, then President of the Institution.

During the decade from 1913 to 1922, I had conducted extensive excavations for the University of Colorado Museum and the American Museum of Natural History in the La Plata Valley, which lies just east of Mesa Verde National Park, Colorado. These excavations had revealed in major outline the chronological stages of aboriginal culture for the region, but there remained some important lacunae to be filled in. To this end, the summer of 1930 was spent in further excavation at key sites along the La Plata River. The results of these investigations were presented in *Archaeological Studies in the La Plata District,* C.I.W. Publication 519.

In the spring of 1930 word came to me of the existence of a series of shallow caves in the canyon-mesa country between the Carriso and Lukachukai mountains in the northeastern corner of Arizona. These shelters had been densely occupied during early stages of Basket Maker–Pueblo inhabitation of the region. They had remained untouched by both specimen hunters and archaeologists, and offered an unparalleled opportunity for a study of the people and of their arts and architecture during the span in which the shelters had served as dwelling and burial places. With a relatively large field party, the summer and fall of 1931 were spent in systematic excavation of the more important of the caves. Study of the vast amount of data and of the voluminous collection of arti-

facts, rich in perishable materials, has continued intermittently up to the present and remains for the most part uncompleted. One paper, however, based principally on materials gathered in 1931, has appeared—*Anasazi Basketry*. This paper, prepared jointly with Robert F. Burgh, is C.I.W. Publication 533.

Early in 1934, my work in the Southwest was briefly interrupted by a trip to Guatemala, in company with Gustav Strömsvik, to re-erect the several stelae which had been thrown down by earthquakes and falling trees in the ancient Maya city of Quirigua. The completion of this task, which took longer than had been anticipated, fell to the more-than-able hands of Strömsvik, because I had to return to the United States to assume another assignment. Drs. Merriam and Kidder had agreed to contribute my services for as much of the year as necessary to the National Park Service in order that I might supervise ruin repair and restoration in Mesa Verde National Park, Colorado, and at the Aztec Ruin National Monument in New Mexico. This work began in April and continued until late autumn. In its course, the weaker parts of Cliff Palace and Balcony House were thoroughly stabilized, and the most urgent repairs were accomplished in several minor ruins in the National Park. At Aztec, the major accomplishment was the restoration of the House of the Great Kiva. This structure had been cleared by me in 1921 while I was excavating the Aztec Ruin for the American Museum of Natural History, before it became a National Monument. On the basis of data recovered during excavation, the superceremonial structure was completely rebuilt, and it stands today as the best exemplification of the highest architectural accomplishment ever to be attained by Pueblo people.

In 1937 local residents reported the finding of some very primitive sites in the Animas Valley, north of Durango, Colorado. These proved to represent the prepottery horizon technically known as Basket Maker II, the earliest stage so far discovered in the Basket Maker—Pueblo culture cycle. No comparable sites had been found anywhere else in the entire Pueblo domain, and their exploration was imperative. There resulted two seasons of field work, filling the summers of 1938 and 1940. What had previously been known of Basket Maker culture had been learned almost wholly from burials and caches in ledge shelters that had not served as dwelling places. In contrast, the Durango sites had been residential. They yielded the first proof of a definite style of domestic architecture for the Basket Maker II period, and provided a broad array of everyday tools of bone and stone which aided greatly in filling out a rounded picture of Basket Maker culture. Incidentally, the earliest positively established date (dendrochronology) in Basket Maker–Pueblo history, A.D. 46, was derived from sections of wood obtained at these sites. The Durango findings were prepared in collaboration with Robert F. Burgh and printed as *Basket Maker II Sites near Durango, Colorado,* C.I.W. Publication 604, brought out in 1954.

It is my intention, despite retirement, to continue work as long as possible on unfinished manuscripts.

Publications

Margaret W. Harrison

The long-awaited *Bonampak, Chiapas, Mexico* (Publication 602), by Karl Ruppert, J. Eric S. Thompson, and Tatiana Proskouriakoff, was received from the printer in May 1955. The mural paintings at this site were copied in water color at one-fourth their original size by Antonio Tejeda F. from accurate measured drawings and color notes made during the expeditions of 1947 and 1948, and were finished in Guatemala City. The water colors, now in the possession of Peabody Museum of American Archaeology and Ethnology, Harvard University, are here reproduced by seven-color offset at one-sixteenth the size of the murals. Rutherford J. Gettens, of the Fogg Art Museum, Harvard Univer-

sity, identified the pigments in the paintings at Bonampak. The text of this publication covers the geography and history of the site, its architecture, its sculptural art, and the hieroglyphic texts on its monuments. The murals are discussed as to their artistic aspects, subject matter, and ethnological implications. Sets of the illustrations have also been issued separately, accompanied by text in pamphlet form (Supplementary Publication 46) written for the layman.

Late in 1954 *Basket Maker II Sites near Durango, Colorado* (Publication 604), by Earl H. Morris and Robert F. Burgh, was published. This report, printed in the same format as Contributions 57 and 58, presents the results of archaeological field work in 1938 and 1940 in the Animas Valley north of Durango, La Plata County, Colorado. Several collaborators recorded in appendixes material related to the archaeological studies: pictographs, by Helen S. Daniels; skeletons, by Charles E. Snow, Professor of Anthropology, University of Kentucky, and William T. Sanders, later Carnegie Institution Fellow in the Department of Archaeology; plant materials, by Volney H. Jones and Robert L. Fonner, of the Museum of Anthropology, University of Michigan; animal and bird bones, by Hugo G. Rodeck, Director of the Museum, University of Colorado.

The first two papers in volume XII of Contributions to American Anthropology and History (Publication 606) appeared in July and November, respectively, of 1954: *The Maya Katun Prophecies of the Books of Chilam Balam, Series I* (no. 57), by Ralph L. Roys; and *Varieties of Classic Central Veracruz Sculpture* (no. 58), by Tatiana Proskouriakoff. These Contributions, composed on the IBM typewriter in the Institution's Office of Publications and printed by offset, were issued as preprints. All future papers in this series will be issued in similar format, thus enabling the material to reach readers with a minimum of delay.

Archaeological Reconnaissance in Central Guatemala (Publication 608), by A. Ledyard Smith, has gone to final press. Like the Contributions, this book was composed on the IBM typewriter; both text and illustrations were printed by offset throughout. The report covers sixty-eight sites in the highland area; some were briefly explored, others were mapped and excavated in varying degrees of intensity.

Anna O. Shepard's *Ceramics for the Archaeologist* (Publication 609) is in page proof. It has been composed on the Photon machine, a photographic typesetting device, and will be printed by offset throughout. In this book the author discusses the composition, sources, and properties of ceramic materials; ceramic processes and techniques of prewheel potters; ceramic analysis and description; problems of pottery classification; and interpretations of ceramic data. Five appendixes provide more technical detail. A list of titles for suggested reading is appended to the bibliography.

Selected References on the Maya Area, compiled by Margaret W. Harrison, was revised as of October 1954 and reissued at that time.

To the fifth volume of Notes on Middle American Archaeology and Ethnology were added three papers: *Drawings of Glyphs of Structure XVIII, Palenque* (no. 119), by Miguel Angel Fernandez, with notes by Heinrich Berlin; *Memoranda on Some Dates at Palenque, Chiapas* (no. 120), by J. Eric S. Thompson; and *Snares and Traps in Codex Madrid* (no. 121), by José Luis Franco.

The second volume of Current Reports began with ten papers: *The Northern Terminus of the Principal Sacbe at Mayapan* (no. 15), by H. E. D. Pollock; *A Round Temple at Mayapan, Yucatan* (no. 16), by Edwin M. Shook; *Excavations in House Mounds at Mayapan: III* (no. 17), by Karl Ruppert and A. Ledyard Smith; *Exploration on the Outskirts of Mayapan* (no. 18), by Robert E. Smith;

A Presumed Residence of the Nobility at Mayapan (no. 19), by J. Eric S. Thompson; *The Temple of Kukulcan at Mayapan* (no. 20), by Edwin M. Shook; *Excavations in Three Ceremonial Structures at Mayapan* (no. 21), by Philip E. Smith; *Colonnaded Buildings at Mayapan* (no. 22), by Edwin M. Shook and William N. Irving; *Exploration in Quintana Roo* (no. 23), by Gustav Strömsvik, H. E. D. Pollock, and Heinrich Berlin; and *An Archaeological Reconnaissance of Northern Quintana Roo* (no. 24), by William T. Sanders.

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